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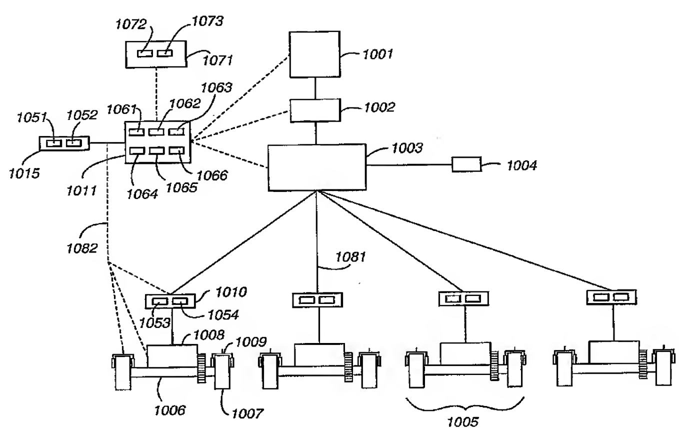
(54) Title: A METHOD FOR MONITORING AND CONTROLLING LOCOMOTIVES




(57) Abstract: The present invention is directed to a locomotive comprising energy storage units such as batteries, a prime energy source (1001), such as a diesel engine, and an energy conversion device (1002), such as a generator. The locomotive comprises one or more of the following features: a separate chopper circuit (1010) for each traction motor (1008); energy storage units (1003) that can be switched from parallel to series electrical connections, a fluid-activated anti-lock brake system (1009), a controller (1015) operable to control separately and independently each axle(1006)/traction motor (1008), and a controller (1051) operable to control automatically a speed of the locomotive. The present invention includes an integrated system for monitoring, controlling and optimizing an electrically powered locomotive using a combination of sensors and software to provide feedback that optimizes power train efficiency and individual drive axle (1006) performance for a locomotive that utilizes one of several possible electrical energy storage systems to provide the tractive power. The net result is a locomotive that has an integrated system of control over all aspects of the locomotive power train including control over individual drive axles (1006), especially during acceleration, braking and non-synchronous wheel slip.

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# A METHOD FOR MONITORING AND CONTROLLING LOCOMOTIVES

## FIELD OF INVENTION

The present invention relates generally to a method and system for optimizing the performance and maintenance profile of a locomotive by exercising control over various aspects of the drive train including control over individual drive axles.

## BACKGROUND OF THE INVENTION

Existing railroad locomotives are typically powered by diesel electric engines in which a diesel motor drives an electric generator to produce electric power to drive electric motors which in turn drive the drive wheels of the locomotive. The present inventor has disclosed the use of a gas turbine engine fueled by compressed natural gas in substitution for the traditional diesel engine in his U.S. Pat. No. 5,129,328 issued July 14, 1992, and as a booster unit for the diesel engine in his U.S. Pat. No. 4,900,944 issued Feb. 13, 1990, both of which are incorporated herein by reference.

The use of energy storage batteries in combination with a generator is known for automobiles, buses and other road and highway vehicles. Such hybrid engines for vehicles are advantageous due to their increased fuel efficiency and reduced pollution. In those applications, it is important to minimize the weight of the batteries to maintain fuel efficiency. Electric batteries have been used to store electric power to drive electric locomotives as, for example, disclosed by Manns in U.S. Patent No. 1,377,087 issued May 3, 1921 which is incorporated herein by reference. In Manns, three standard diesel engines are used to drive generators to charge the storage batteries. Such a system has not achieved commercial acceptance over existing diesel electric locomotives due to the added cost and complexity of providing multiple diesel engines in addition to the storage batteries.

The present inventor has also disclosed the use of a battery powered locomotive which has a ratio of energy storage capacity to charging power in the range of 6 to 40 hours in his U.S. Patent No. 6,308,639 issued October 30, 2001 which is also incorporated herein by reference.

The present inventor has also disclosed the use of individual chopper circuits associated with individual drive axles in his copending U.S. Patent Application S/N 10,083,587 filed on February 26, 2002.

There remains a need for a fuel-efficient locomotive which uses a combination of a small fuel-powered generator, a substantial energy storage capacity, and control systems that regulates and maintains the power train at maximum fuel efficiency and minimizes maintenance. Such control systems would also allow greater command over individual drive axles to help alleviate undesirable conditions such as non-synchronous wheel slippage and wheel locking.

## SUMMARY OF THE INVENTION

These and other needs are addressed by the various embodiments and configurations of the present invention. The present invention is directed generally to an integrated method for monitoring, controlling, and/or optimizing an electrically powered locomotive.

In a first embodiment, each axle assembly, which is typically an axle, a traction motor, and two wheels, is monitored and controlled independently using one or more sensors and a control feedback loop. The locomotive typically includes a plurality of axle assemblies, a primary energy source, an energy storage unit, and an energy conversion device to convert the energy output by the primary energy source into a form suitable for storage in the energy storage unit.

For example, in one configuration an individual chopper circuit is provided for each traction motor. Each chopper circuit typically includes a drive switch, a free-wheeling bypass, which further includes a free-wheeling gate, and a filter to absorb voltage transients and smooth motor current ripples during switching. During any selected time interval, each chopper circuit is either in the driven or free-wheeling mode. In the driven mode, the drive switch is conducting and a power pulse is provided to the traction motor. In the free-wheeling mode, the drive switch is non-conducting and the power pulse circulates through the free-wheeling bypass circuit. By time sequencing the power pulses to individual traction motors, the current draw on the energy storage system can be minimized over a significant portion of the operating range since instantaneous current requirements from individual motors are not additive. This independence of individual current requirements can have the positive effect of reducing both the impedance seen by the energy storage unit and the internal resistive losses sustained in the energy storage unit. The flexibility of individually controlling power to the traction motors can be an efficient and effective approach to

correcting non-synchronous wheel slip. The simplified circuit affords a straightforward means of smoothly removing and then restoring power to a slipping wheel while maintaining the pre-slip level of power to the wheels not experiencing slip. This can have the advantage of significantly reducing the power requirements and tread wear typically experienced with incidents of non-synchronous wheel slip.

In yet another example, the revolutions per minute of each axle are monitored to detect wheel slip during locomotive acceleration or wheel lock during braking. As will be appreciated, wheel lock can occur when brakes are applied and are either slow or unable to release upon command. When the revolutions per minute exceed a selected threshold, the controller assumes that the wheels on the axle are slipping and controls power to the respective traction motor as set forth above. When the revolutions per minute are at or near zero when the brakes have been applied or after brakes have been released, the controller assumes, if other motion detectors such as, for example, a doppler radar system indicates locomotive movement, that the brakes are locked and selectively applies a pressurized fluid, such as air, to a fluid-activated brake release. The pressurized fluid is forced through ports in the brake shoe (or pad in the case of disc brakes) and against the braking surface to forcibly release the brake shoe or pad from the braking surface.

In yet another embodiment, a controller controls an excitation circuit to the energy conversion device to control the load on the primary energy source. There are two methodologies for controlling the excitation circuit. First, when a first predetermined set point is exceeded by a first monitored parameter, the excitation current is increased and, when a second predetermined set point exceeds the first monitored parameter, the excitation current is decreased. The first monitored parameter is revolutions per minute of a mechanical component of the prime energy source. Second, when the first predetermined set point is exceeded by a second monitored parameter, the excitation current is decreased and, when the second predetermined set point exceeds the second monitored parameter, the excitation current is increased. The second monitored parameter is the output power of the energy conversion device. In this manner, the primary energy source, when operating, can be reliably maintained at or near a peak fuel efficiency, maximum torque, maximum power or any other desired engine operating condition.

In yet another embodiment, a controller is configured to provide reliable speed control for the locomotive. The velocity of the locomotive may be controlled by two primary techniques. In a first technique, a substantially constant power is maintained across each of the plurality of traction motors. As will be appreciated, the power is related to the specified velocity. In a second technique, the revolutions per minute of each of the plurality of axles are maintained at a rate related to the specified velocity. In these techniques, the individual monitoring of the power and/or revolutions per minute of each axle assembly can permit different powers pulses to be applied across each traction motor. Such selective power pulse application can take into account operational differences among the axle assemblies, such as differently sized wheels, traction motors of differing efficiencies, and the like.

In another embodiment, the energy storage unit of the locomotive is configured as a bank of capacitors which store at least most of the electrical energy. A pulse forming network can be provided to convert the output of the capacitors to a form acceptable to the traction motors. This embodiment would be preferred if a bank of capacitors have a higher energy density than a battery pack of comparable storage capacity.

In a preferred embodiment, a controller unit and system of sensors is used to monitor, synchronize and optimize the operation of the locomotive drive train as well as the individual drive axles especially during acceleration and braking. The controller also provides the locomotive operator with information through a system of performance data and warnings that allow the operator to manually override various functions in an emergency. The information and warnings may be provided by conventional means such as warning lights and bells and the like, or by these conventional means supplemented by and by a computer console that can access a variety of control and informational screens.

These and other advantages will be apparent from the disclosure of the invention(s) contained herein.

The above-described embodiments and configurations are neither complete nor exhaustive. As will be appreciated, other embodiments of the invention are possible utilizing, alone or in combination, one or more of the features set forth above or described in detail below.

## BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows the principal elements of the preferred embodiment.

Figure 2 shows a schematic representation of sensor locations for monitoring the power, charging and braking systems of a battery-powered locomotive.

Figure 3 shows an electrical schematic of a motor generator with exciter field control.

Figure 4 is a schematic representation of the elements of an energy storage battery pack.

Figure 5 shows a schematic of a typical chopper circuit illustrating the free-wheeling current path.

Figure 6 shows an electrical schematic of a battery energy storage system powering four DC traction motors.

Figure 7 shows a sequence of non-overlapping short power pulses as might be provided by the circuit of Figure 6.

Figure 8 shows a sequence of power pulses that do not overlap but also do not have any intervening space as might be provided by the circuit of Figure 6.

Figure 9 shows a sequence of power pulses that have some overlap as might be provided by the circuit of Figure 6.

Figure 10 shows a sequence of power pulses that have substantial overlap as might be provided by the circuit of Figure 6.

Figure 11 shows a sequence of power pulses that have continuous overlap as might be provided by the circuit of Figure 6.

Figure 12 shows a schematic drawing of a brake shoe with provisions for an air-actuated release mechanism.

Figure 13 shows a flow diagram for the logic for main power control of a battery-powered locomotive.

Figure 14 shows a flow diagram for the logic for a fuel-efficient charging control for the charging apparatus of a battery-powered locomotive.

Figure 15 shows a flow diagram for the logic for an air-braking and wheel lock release system for use on rail cars and locomotives.

Figure 16 shows a flow diagram for the touch screen information and control system.

Figure 17 shows an example of a main menu screen.

Figure 18 shows an example of a traction motor summary screen.

Figure 19 shows an example of an individual traction motor screen.

Figure 20 shows an example of a battery status screen.

Figure 21 shows an example of a battery monitoring system screen

Figure 22 shows an example of a control tools screen

Figure 23 shows an example of an alarm history screen

Figure 24 shows an example of a digital input monitor screen

Figure 25 shows an example of an output monitor screen

Figure 26 shows an example of a warnings screen

Figure 27 shows an example of a derate and shutdown screen

## DETAILED DESCRIPTION OF THE DRAWINGS

The present invention discloses an integrated method for monitoring, controlling and optimizing an electrically powered locomotive using a combination of sensors and software to provide feedback that optimizes power train efficiency and individual drive axle performance for a locomotive that utilizes one of several possible electrical energy storage systems to provide the tractive power. A drive axle is comprised of a DC traction motor, an axle and two wheels. The locomotive includes at least two drive axles and can typically include as many as 8 drive axles. In addition to utilizing an electrical energy storage system and individual chopper circuits for each of a subset of drive axles (which typically is an individual chopper circuit for each drive axle), the present invention incorporates a comprehensive logic and software system to monitor, control and optimize the flow of power in the locomotive. This system includes a method of load control for the prime energy source; a method of releasing locked wheels; and a method of accurately controlling the speed of the locomotive in the low speed range. The net result is a locomotive that has an integrated system of control over all aspects of the locomotive power train including control over individual drive axles, especially during acceleration and braking.

The locomotive power train generally includes the following principal elements as shown in Figure 1. A prime energy source 1001 provides the basic energy to the system. The prime energy source 1001 drives an apparatus or device 1002 for converting mechanical energy of the prime energy source to a direct current ("DC") output charging source. A

prime energy storage unit or device 1003 stores electrical energy delivered by the conversion apparatus 1002 and provides most of the power for the traction motors. The locomotive may also include a number of auxiliary systems represented here as a single element 1004. These include, for example, auxiliary compressors (not shown), auxiliary power supplies (not shown) of various voltages, heating and cooling systems (not shown), and lighting and auxiliary control equipment (not shown). In the present invention, power is supplied to these auxiliary systems 1004, as required, by the main energy storage system 1003 since the charging source 1002 may or may not be operating.

The locomotive may have a plurality of axle assemblies1005, each of which is comprised of an axle 1006, wheels 1007, a traction motor 1008 and an air-brake 1009. The air-brake 1009 may be a conventional disc or tread type rail braking system or it may be a conventional braking system that includes an air-activated brake release system used in wheel-lock situations, such as described in Figure 18. In the present invention, each axle assembly 1005 with a traction motor 1008 has a chopper circuit 1010 associated with it. Each chopper circuit 1010 derives its power from the energy storage device 1003 and allocates and configures the power flow from the energy storage unit 1003 to at least two of, and typically each of, the DC traction motors 1008.

In the present invention, a locomotive master chopper control system 1015 and individual axle chopper circuits 1010 provide a method of controlling power provided from the energy storage unit 1003 to the direct current traction motors 1008. This method generally includes the steps of: a) determining the power requirement for each motor 1008 at each of a number of discrete, successive time intervals; b) determining the necessary effective power pulse width, amplitude and spacing to achieve the desired power for each motor 1008 during a selected time interval; c) sequentially pulsing power to at least some of the motors 1008 during the selected or a subsequent time interval for a duration (or length of time) necessary to achieve the power requirement at each time interval.

The individual chopper circuits 1010 receive timing and power instructions from the locomotive master chopper control system 1015 which includes a master clock 1051 (an integrated circuit that generates a series of pulses) and pulse sequencer 1052 (an integrated circuit that sequences the pulses into uniform periods for purposes of the pulse width regions for each motor). Each chopper circuit 1010 includes at least its own: pulse width

modulator 1053 (provides 'clipped' triangular waveforms that result in the creation of a series of pulses, which is used essentially to toggle the power switch devices on and off according to the pulses); and drive switch 1054 (insulated gate bipolar transistors, abbreviated as IGBTs, that are switching devices capable of sequentially 'pulsing' the power source to the different motors at a very fast rate). A latching circuit (not shown), can also be provided that is set so that after the IGBT has failed to fully saturate or a fault current has been detected, it will interrupt the drive to the IGBT. This forces the IGBT off and prevents the IGBT from operating into a short circuit. The latching circuit can be provided by an electronic circuit board or by software logic associated with logic unit 1011 described below.

All of the principal elements of the locomotive are monitored, co-ordinated and controlled by a such as, for example, a Programmable Logic Circuit ("PLC"), a micro-controller, or an industrial computer. The logic unit 1011 includes: a ramping function 1061 (logic to ramp requested throttle level at a rate that is reasonable for the locomotive); a power dispatch logic 1062 (central logic that evaluates any pertinent derate conditions, any wheel slip, as well as the requested throttle level, to determine the appropriate power level to be sent to the pulse width modulation module 1053); an detection scaling function 1063 (logic for determining non-optimal performance, such as wheel slip. Power reduction to individual motors can be put in place in the case of differential wheel slip and overall power is reduced in the case of synchronous wheel slip); a derate evaluation logic 1064 (logic to reduce the power demand below that requested by the operator for protection of equipment. This could include reducing power in case equipment is at risk of overheating or currents climb close to equipment design limits); a brake control logic 1065 (control of the air brake system including individual axle wheel lock release); and a generator 1002 load control logic 1066 (control of the generator 1002 excitation field to maintain the prime energy source 1001 at approximately peak fuel efficiency or other desired condition). The logic unit 1011 receives the information from an operator input device 1071 which includes a throttle setting 1072 and a speed setting 1073. The throttle 1072 is typically a throttle notch between idle and eight positions but also could be an electronic device, such as an infinitely variable control or a touch screen. The speed setting 1073 is typically a rheostat motor voltage control but also could be an electronic device, such as an infinitely variable control or a touch screen. The logic unit 1011 also receives the input information on the status of various

components of the system from several sensing devices described below in Figure 2. As discussed above, the logic device 1011 processes all the input information and sends out instructions to co-ordinate the operation of: the prime energy source; the DC conversion apparatus; the charging and discharging of the energy storage unit; the DC traction motor electrical controllers; the DC traction motors; and the braking system on the individual axle assemblies 1005. The continuous lines 1081 connecting various elements represent physical connections and the dashed lines 1082 connecting various elements represent simplified electrical control and informational linkages. It should be noted that the control and informational linkages shown apply to all the axle assemblies 1005, even though the connections are shown only to the first assembly.

The prime energy source can be any suitable power or energy source such as for example a reciprocating diesel engine, a gas turbine engine, a small diesel reciprocating engine, a microturbine, a fuel cell. Alternately, prime energy can be provided by an external source such as overhead electrical trolley wires or directly plugging into a utility grid. The prime energy source 1001 is preferably a high-efficiency reciprocating diesel engine with a preferred power rating approximately in the range of about 25 to 250 kW. With reference to the energy storage unit 1003, the preferred range of the ratio of energy storage capacity to charging power of the generator is in the range of about 6 hours to 40 hours. When charging is required, it is more preferable for the prime energy source 1001 to be operated at or near its peak fuel efficiency rating which is preferably in the range of approximately 12 to 16 kwh per gallon of fuel for a small diesel engine. It may also be preferable for the prime energy source 1001 to be operated at or near its peak torque or power rating under certain circumstances and these operating regimes would require different set points. Otherwise, when the energy of the energy storage unit 1003 is at its full rated storage capacity (as determined, for example, by an upper voltage set point in the case of a battery pack), the prime energy source 1001 is preferably turned off. The prime energy source 1001 may also be turned off when, for example, the locomotive is operating in a confined space, such, as for example, a locomotive maintenance shed.

The conversion apparatus 1002 typically converts mechanical energy form the prime energy source 1001 to direct current (DC) electrical energy and the conversion is preferably effected by an alternator which outputs rectified DC power to an energy storage device 1003.

The alternator is preferably driven by the prime energy source. The charging generator 1002 is preferably an alternator that operates in the approximate the range of about 50 to 75 Hertz. The alternator is driven by the prime energy source and may contain a means for converting alternating ("AC") electrical power to direct current ("DC") electrical power. The alternator power output is preferably controlled by varying the excitation current to the alternator field coils.

The control of the power output of the DC charging system 1002 to the energy storage unit 1003 can be accomplished, for example, by varying the excitation current provided to the alternator 1002 to maintain an at least substantially constant power output to the energy storage unit 1003, while appearing as an approximately constant load to the prime energy source 1001. There are typically at least two techniques of controlling the output of the charging generator 1002 to effect load control for the diesel engine. In a first technique, the RPMs of the diesel engine are monitored such as, for example, by a tachometer and the RPMs are maintained within a range which is defined by upper and lower RPM set points. This range is selected for maximum fuel efficiency of the prime energy source. If the RPMs fall below the selected range (indicating a heavy load on the engine), then the excitation current to the alternator can be reduced to reduce the power output of the alternator until the engine RPMs are restored to within the desired range. If the RPMs rise above the selected range (indicating a light load on the engine), then the excitation current to the alternator can be increased to increase the power output of the alternator until the engine RPMs are restored to within the desired range. In a second technique, the DC output power of the alternator is monitored as determined by the product of the measured output volts and amperes. If the output power falls below the lower set point of the selected output power range, then the excitation current to the alternator can be increased to restore the power output to within the desired range. If the output power rises above the upper set point of the selected range (presenting a heavy load to the engine), then the excitation current to the alternator can be decreased to reduce the power output to within the desired range. In this technique, the RPMs of the engine can also be monitored to ensure that the RPMs stay within the range selected for maximum fuel efficiency. If they fall outside the selected range, then the excitation current to the alternator can be further modified to bring the engine RPMs back into the desired range.

In the event that prime energy is provided by an external source such as overhead trolley wires or plugging into a utility grid, the charging system 1002 would be replaced by a voltage step-up or step-down apparatus and, if required, a converter from AC to DC power so as to provide the proper driving voltage to charge the energy storage unit 1003.

The electrical controller 1010 for each DC traction motor 1008 is preferably a chopper circuit such as disclosed in copending U.S. Patent Application S/N 10,083,587, which is incorporated herein by this reference. The chopper circuit and control system, as applied in the present invention, are discussed more fully in Figures 8 and 9.

The energy storage unit 1003 may be any other suitable electrical storage device, such as for example an energy storage capacitor bank, a flywheel generator system of which a homopolar generator is an example. The energy storage unit is typically composed of a plurality of subunits, such as batteries and/or storage capacitors. The energy storage unit 1003 is preferably an electrical energy storage battery pack. The electrical generator 1002 provides DC power to the energy storage unit 1003 at an at least substantially constant power, with the output voltage being higher than the maximum voltage of the battery pack. The battery pack typically has a maximum voltage, usually input as an upper set point to avoid gas generation or other damage to the battery cells and a minimum voltage usually input as a lower set point to avoid seriously diminishing the recharge capacity of the battery plates. The upper and lower set points define the operational range of the battery voltage. The charging generator is preferably always in operation when the battery voltage is below the lower set point. The charging generator is usually in operation when the battery voltage is below the upper set point. An exception might be when the locomotive is operating in, for example, a confined space, where emissions from the prime energy source would be undesirable. The charging generator is most preferably not in operation when the battery voltage is above the upper set point.

A new method of setting the upper and lower set points that define the operational range of the energy storage unit is disclosed. Typically, the upper and lower voltage set points of the energy storage unit are selected by picking an upper voltage and a lower voltage based on experience. In the new method, the quantity of charge in the energy storage unit is accounted for by continuously (by analogue or digital sampling) measuring the current flow to and from the energy storage unit and integrating the current time history to determine

the state of charge in the energy storage unit. The location of the current sensor used to apply this method is shown in Figure 9. Using this technique, if the total charge in the energy storage device falls below the upper set point of the selected range, then the charging generator is turned on. If the total charge rises above the upper set point of the selected range, then the charging generator is turned off. In the accounting of charge in the energy storage unit, a small amount of charge (typically 1 or 2% of the total charge) is lost to the system through various inefficiencies and this loss is estimated and added to the charge total to maintain an accurate accounting. Either of the above methods may be used separately or in combination to obtain better control over the charging process for the energy storage device to maintain it within its optimum operating range. The same techniques may be used if the energy storage device is a battery pack or a capacitor bank.

As part of its air-braking system, the locomotive may also include a system 1009 for releasing wheels that become locked during air braking. This wheel release system is discussed more fully in Figure 18.

To provide the information necessary to synchronize the operation of the various components of the locomotive drive train, including, if necessary, the operation of individual axles, an appropriate placement of sensors monitors and measures a plurality of parameters as illustrated by Figure 2. Here, voltage sensors are represented by solid circles; current sensors by a solid square "C" symbol; temperature sensors by a solid rectangle; rotary speed sensors by a solid triangle with vertex pointing up; and pressure sensors by a solid triangle with vertex pointing down. Voltage sensors include voltmeters, other common voltage transducers or voltage sensing devices; current sensors include current-sensing resistors, Hall current sensors, current-sensing transformers, current transducers, Rogowski coils or other common current measuring devices; rotary speed sensors include tachometer, axle alternators and the like; temperature sensors include thermocouples, thermistors, semi-conductors or other common temperature measuring devices and; pressure sensors include pressure transducers, pressure gages or other common pressure measuring devices. With reference to Figure 2, the operating characteristics of the prime energy source 2001 such as, for example, the revolutions per minute (RPMs) of an internal combustion engine are measured by a first rotary speed sensor 2012; engine temperature by a first temperature sensor 2022 and engine oil pressure by first pressure sensor 2023. The RPMs of the prime energy source

2001 can also be determined from monitoring the power frequency of the conversion device 2002 (as indicated in Figure 28). The field excitation current for the conversion device 2002 is sensed by a first current sensor 2024 and the temperature of the conversion device 2002 is measured by a second temperature sensor 2025. The DC output voltage and current are measured for the conversion device 2002, by a first voltage sensor 2026 and second current sensor 2027. The voltage at several locations of the energy storage unit 2003 may be measured using additional voltage sensors 2031 and the temperature at several locations of the energy storage unit 2003 may be measured using additional temperature sensors 2032. In addition, the output voltage and current are measured for the energy storage unit 2003 by a second voltage sensor 2033 and third current sensor 2034. The current to each IGBT 2028 on the individual chopper circuits2007 are measured by additional current sensors 2035. The current to each traction motor 2004 is measured by additional current sensors 2041; the voltage across all or a portion of each traction motor 2004 may be measured by additional voltage sensors 2042; and the temperature the voltage representative of each each traction motor 2004 may be measured by additional temperature sensors 2043. The rotational speed of a plurality of, and typically each, drive axle 2005 of the locomotive is measured by additional rotary speed sensors 2051. The air pressure in various locations of the locomotive braking system 2006, including locations where wheel release devices may be used, are monitored by additional pressure sensors 2061 and the temperature representative of the brake shoes 2009 may be measured by additional temperature sensors 2062. The locomotive will typically also have a doppler radar detector (not shown) that can independently determine locomotive speed. This system provides an indication of locomotive speed independent of the axle rotary speed sensors 2051 which cannot properly indicate locomotive speed when there is a synchronous wheel slip or synchronous wheel locking condition.

An example of a charging generator circuit is shown in Figure 3 which shows an exciter coil that can be independently controlled. A stator 3001 generates an alternating current which is rectified by power diodes 3002. The rectified power is then fed to the prime energy storage source 3003 shown here as a storage battery. The rectified power is also provided to various auxiliary systems (not shown) such as for example blower and fan motors, lighting and compressors and the like. The output of the stator 3001 is controlled by

an independently controlled exciter coil 3004. The output power to the energy storage source 3003 is monitored by a current transducer 3005 and a voltage sensor 3006. The generator excitation board 3007 receives its inputs from a computer control system via path 3008 or, in an emergency (such as from detection of an anomalously high voltage output from the generator, for example), from path 3009 originating from the voltage sensed across the stator 3001. In the case of such an emergency, the excitation board 3007 has the ability to override the control of the main logic controller and directly reduce the current to the excitation field coil 3004.

Referring to Figure 1, the preferred energy storage unit 1003 is a battery pack. The battery pack may be divided into a plurality of racks. The racks mechanically and removably house the individual battery units to facilitate maintenance and replacement. The racks contain a plurality of individual battery units or other types of energy storage subunits, such as capacitors. The battery units are each comprised of a set number of cells. The preferred cells are those of a lead-acid type which has an electrochemical potential of about 2.13 volts, the highest currently available in rechargeable battery chemistry. The definition of these divisions are illustrated in Figures 4a, b and c which are a schematic representation of the elements of an energy storage battery pack. In Figure 4a, a battery unit 4001 is comprised of individual cells 4002 , a positive terminal 4003 and a negative terminal 4004. The number of cells 4002 is preferably in the range of 1 to 10 and most preferably in the range of 1 to 6. The fewer cells 4002, the easier it may be to replace battery units that become degraded or fail. As shown in Figure 4b, battery units 4006 may be assembled together in a battery rack 4005. The battery rack 4005 is typically an assemblage of a convenient number of battery units 4006 that allow for easy maintenance or assembly into groups that are connected in series or in parallel. The number of battery units 4006 in a battery rack 4005 is preferably in the range of 2 to 50 and more preferably in the range of 4 to 16. Referring to Figure 4c, battery racks 4008 may be assembled to form a battery pack 4007 which is largest division considered in the present invention. The number of battery racks 4008 in a battery pack 4007 is preferably in the range of 4 to 100 and more preferably in the range of 10 to 60. The entire battery pack 4007 has a a positive terminal 4009 and a negative terminal 4010. If a high energy capacitor bank is used as the energy storage method, the same definitions may be used

with battery units replaced by capacitors, the battery rack by a capacitor rack and the battery pack by a capacitor bank.

In a preferred embodiment, all of the battery units are connected electrically in series so that the capacity rating of the battery pack, expressed in ampere-hours, is the same as the rating of each battery unit. In this embodiment, the voltage output of the battery pack is the sum of the terminal voltages of all the battery units. The same configuration may be used with battery units replaced by capacitors.

This invention most preferably utilizes individual chopper circuits to control direct current to each DC traction motors. DC motors have performed as the motive force in a variety of applications including locomotives where, typically, multiple direct current motors are used. For example, locomotives may employ 2 to 8 driving axles, each driving axle having one DC traction motor.

It is known in the art to control the speed of a direct current series motor by using a chopper circuit which includes a main switch device in series with the motor and a bypass current path. This is a more efficient form of power control for locomotives than using resistance control systems. With a chopper circuit, the control of the speed of the traction motor is achieved by varying the power pulses supplied to the motor so that average power supplied is what is required and power is not wasted by dissipation in resistance control systems. A thyristor is one type of main switch device used in early chopper circuits. It has since been replaced by the more versatile Insulated Gate Bipolar Transistors ("IGBTs").

The main elements of a typical chopper circuit, as used in the present invention, are shown in Figure 5. The chopper circuit has input terminals 5001 through which current flows into the circuit. The main current flow is along path 5004 which passes through an IGBT switch 5003 and a traction motor 5002. The main current path 5004 is active when the input power source (not shown) is powering the traction motor 5002. When the IGBT 5003 is switched to its off position, current is forced to flow through the free-wheeling path 5006 by the free-wheeling gate 5005, which is shown as being a diode. The chopper circuit thus controls the speed of the motor by switching the input voltage on and off depending on what average output power is required; the longer the chopper is switched on, the higher the average output power. The time interval during which the chopper is switched on is known as the on-time; the interval during which the chopper is switched off is known as the off-

time. The ratio of the on-time of the power pulse to the off-time of the power pulse is often referred to as the-mark-to-space ratio or chopper ratio. The elements comprising a typical chopper circuit are discussed above as part of the detailed description of Figure 1.

In the present invention, there is preferably a chopper circuit, including its free-wheeling gate, associated with each traction motor. In other words, each motor typically has, in addition to a corresponding main current path and main drive (or chopper) switch, a corresponding free-wheeling path and free-wheeling gate. This is illustrated in Figure 6 which shows four traction motors, each having an individual chopper circuit. The main drive switches are shown here as Insulated Gate Bipolar Transistors ("IGBTs") that are switching devices that do not require commutating and are capable of sequentially pulsing the power source to the different motors at a very fast rate. Figure 6 shows an example of an electrical schematic for a battery energy storage system providing power for four DC traction motors. The battery pack 6001 is shown in two sections separated by an emergency manual disconnect 6002. The battery pack is connected to the traction motor system 6005 by disconnect switches 6003 which are controlled by the locomotive computer system. A large bank of surge capacitors 6004 are connected across the battery pack. The battery pack voltage is monitored by voltage sensor 6021 and the battery pack output current is measured by current sensor 6022. The current sensor 6022 is used in the determination of the state of charge of the battery pack as discussed above with reference to Figure 1 which discusses this method of setting the upper and lower set points that define the operational range of the energy storage unit.

The four traction motor systems 6005 are shown here connected in parallel with the battery pack 6001. Four DC traction motors 6006 are shown, each associated with its own individual chopper circuit 6007. Each of the traction motors 6006 are comprised of a field coil 6011which is connected to a reverser switch 6012 and an armature 6021; a main circuit path 6009 controlled by an IGBT 6020; a free wheeling circuit path 6008 and free-wheeling gate 6010. The IGBT 6020 is controlled by the locomotive computer system. Each chopper circuit 6007 is protected by a fuse 6013 and a scrubber filter capacitor 6014. Together, the fuse 6013 and filter 6014 act to control the voltage transients as the chopper circuit 6007 switches from pulse or driven mode to free-wheeling mode or visa versa, thus reducing the risk of overheating and extending the lifetime of the IGBT 6020. The filter 6014 also acts

to smooth any rapid current fluctuations through the traction motors 6005 as the chopper circuit 6007 switches from pulse or driven mode to free-wheeling mode or visa versa. The main current through each traction motor 6006 is monitored by a current transducer 6015.

As will be appreciated, in the driven mode, the chopper switch is activated such that the at least most of the current passes along the main current path and through the traction motor while in the free wheeling mode the chopper switch is deactivated such that at least most of the current passes along the free-wheeling or bypass path and through the traction motor. Figure 6 also shows a configuration to effect the switching necessary to reverse the motor direction by reversing the current flow through the field coils.

In prior applications, a single chopper circuit has been used to control the speed of all of the DC traction motors. This has a number of disadvantages. For example, if one of the wheels is slipping (non-synchronous wheel slip), the chopper reduces power to all of the motors which risks further exacerbation of the problem.

Typically, pulses are applied to different motors during discrete (nonoverlapping) time periods. In other words, during a selected first time period (which is a subset of a time interval) a first electrical pulse is applied to a first traction motor but not to a second (different) traction motor, and, during a selected second time period, a second electrical pulse is applied to a second traction motor and not to the first traction motor. Thus, during the selected first time period the first traction motor is in the driven mode while the second traction motor is in the free-wheeling mode and during the selected second time period the first traction motor is in the free-wheeling mode while the second traction motor is in the driven mode.

The advantages of individual chopper circuits with each traction motor are illustrated in Figures 7 through 11 which show an example of sequencing power pulses to four individual motors and the resultant net draw on the energy storage battery, for a number of cases.

Figures 7a, b, c, d and e show a time sequence of short pulses 7001 to each motor typical of locomotive start up at a low throttle condition. The pulses 7001 in each sequence are shown along a time axis 7002 which is a common time axis for each sequence. Since the voltage amplitude of the pulses 7001 is approximately constant for a large energy storage battery pack, the pulse amplitudes 7003 may be considered current or power pulses. Each

motor receives a power pulse 7001 at a different time. Figure 7a represents the pulses provided to a first traction motor; Figure 7b to a second traction motor; Figure 7c to a third traction motor; and Figure 7d to a fourth traction motor. Figure 7e shows the sum of the individual motor sequences 7004 which is also the net power draw from the battery pack. In this case, the battery discharge is intermittent and the battery current draw is equal to the current through each individual motor. In the prior art where all motors are pulsed at the same time, the battery current draw is equal to the sum of the currents through each individual motor. Since battery internal heating is proportional to $I^2R$ where I is the battery current and R is the battery internal resistance, an advantage of the present invention is to minimize battery heating by time spacing the power pulses to each motor. Also, each motor receives a power pulse which is the same amplitude as the output power of the battery pack. As an example, each traction motor has peak power pulses of 1,120 kW and an average power of 140 kW (pulse width is 1/8 of the time between pulses). The battery pack likewise would have peak power pulses of 1,120 kW and an average power output of 560 kW (four motors averaging 140 kW).

Figures 8a, b, c, d and e show a time sequence of pulses to each motor where the pulses 8001 are spaced 8002 such that there is zero time between any two pulses form the four sequences. Figure 8a represents the pulses provided to a first traction motor; Figure 8b to a second traction motor; Figure 8c to a third traction motor; and Figure 8d to a fourth traction motor. Figure 8e shows the sum 8003 of the individual motor sequences which is again is the net power draw from the battery pack. For a four motor locomotive such as shown in Figure 6, this corresponds to pulse widths that are 25% of the time between pulses in an individual sequence. In this case, the battery is operating continuously as shown by its power output 8003. Also for this case, each motor receives a power pulse which is the same amplitude 8004 as the output power 8005 of the battery pack. Assuming the same battery pack and traction motors as used in Figure 7, in the example of Figure 8, each traction motor has peak power pulses of 1,120 kW and an average power of 280 kW (pulse width is 1/4 of the time between pulses). The battery pack now has peak power pulses of 1,120 kW which is the same as its average power output of 1,120 kW.

In the cases illustrated by Figures 7 and 8, only one of the traction motors is in driven mode while the others are all in free-wheeling mode.

Figures 9a, b, c, d and e show a time sequence of power pulses 9001 that have some overlap in time as might be the case for higher locomotive speed or throttle power setting. Figure 9a represents the pulses provided to a first traction motor; Figure 9b to a second traction motor; Figure 9c to a third traction motor; and Figure 9d to a fourth traction motor. Figure 9e shows the sum 9003 of the individual motor sequences which is again is the net power draw from the battery pack. In this case, the battery is operating continuously. Each motor receives a power pulse 9001 which has a constant amplitude 9002. The power draw 9003 on the battery pack is variable, reflecting the overlap in individual motor power pulses. In actual practice, the battery filtering capacitor tends to smooth out the power pulse from that shown. Assuming the same battery pack and traction motors as used in Figure 7, in the example of Figure 9, each traction motor has peak power pulses of 840 kW and an average power of 315 kW (pulse width is 3/8 of the time between pulses). The battery pack now would have peak power pulses of 1,680 kW and an average power output of 1,260 kW.

Figures 10a, b, c, d and e show a time sequence of power pulses 10001 that have substantial overlap in time. In this case, the battery is operating continuously. Figure 10a represents the pulses provided to a first traction motor; Figure 10b to a second traction motor; Figure 10c to a third traction motor; and Figure 10d to a fourth traction motor. Figure 10e shows the sum 10003 of the individual motor sequences which is again is the net power draw from the battery pack. Each motor receives a power pulse 10001 which has a constant amplitude 10002. The power draw 10003 on the battery pack is has increased and remains variable, reflecting even greater overlap in individual motor power pulses. In actual practice, the battery filtering capacitor tends to smooth out the power pulse from that shown. Assuming the same battery pack and traction motors as used in Figure 7, in the example of Figure 10, each traction motor has peak power pulses of 630 kW and an average power of 394 kW (pulse width is 5/8 of the time between pulses). The battery pack now would have peak power pulses of 1,890 kW and an average power output of 1,575 kW.

Figures 11a, b, c, d and e show a time sequence of power pulses 11001 that are continuous and the battery is also operating continuously. Figure 11a represents adjoining pulses provided to a first traction motor; Figure 11b to a second traction motor; Figure 11c to a third traction motor; and Figure 11d to a fourth traction motor. Figure 11e shows the sum of the individual motor sequences 11003 which is again is the net power draw from the

battery pack. In this final case, the battery is operating continuously and each motor receives a power pulse 11002 which is approximately one quarter the amplitude of the output power 11003 of the battery pack. Assuming the same battery pack and traction motors as used in Figure 7, in the example of Figure 11, each traction motor has continuous power of 560 kW and the battery pack has a continuous power draw of 2,240 kW which is four times that of each motor.

In most locomotive operations, the engineer applies power by selecting a throttle setting (usually a notch setting from 1 to 8). The throttle setting causes the logic controller to apply the required power to the traction motors using a preset logic. In some cases, the engineer may want to set a particular locomotive speed, usually a low speed such as, for example, might be required by a switching locomotive. A particular speed setting may be accomplished by the engineer using a rheostat to control power to the traction motors, rather than by selecting one of the throttle notch settings. A more preferred method is for the engineer to set the desired speed by the use of a touch screen or other type of computer input. In the latter case, the speed setting may be accomplished by the logic controller which would prescribe a preset power pulse width setting for the chopper circuits. The power pulse widths would be set, typically to a very short pulse widths, to provide a low average power to the traction motors that is known to result in the desired locomotive speed. More preferably, the logic controller would utilize the tachometers on the drive axles to control the speed of the locomotive to the desired value. This latter approach would result in the desired locomotive speed being more accurately achieved.

If an energy storage capacitor bank is used in place of a battery pack, then the output of the capacitor bank may require additional conditioning to match the voltage-current requirements of DC traction motors. This is because a battery pack provides an approximately constant voltage output over most of its discharge range, whereas a capacitor bank discharges as a decaying voltage waveform. The additional conditioning may be accomplished with yet another chopper circuit, such as for example a buck-boost chopper circuit, or any of a number of well-known pulse forming networks utilized in the high energy capacitor bank industry. Otherwise, the traction motor circuits may be configured identically to those shown in Figure 6.

A truck assembly in the railroad industry is a frame to which one or more axle and wheel assemblies are mounted. The truck assembly also includes suspension and brake system elements. In addition, there are provisions for mounting AC or DC traction motors. The present invention generally utilizes truck assemblies with only DC traction motors.

The primary specifications for DC traction motors used in the present invention are typically:

(a) a power in the range of about 300 to 1,200 horsepower;

(b) a tractive force in the range of up to about 25,000 lbs;

(c) a maximum voltage rating of about 1,300 volts; and

(d) a maximum current rating of about 1,800 amperes for short periods, typically less than 3 minutes, depending on the level of air cooling available.

The braking system on a locomotive is typically an air brake system in which the charging generator or energy storage unit are utilized to operate an auxiliary compressor to pressurize an air reservoir. The air reservoir provides air pressure to the brake cylinders. When activated, air brake cylinders engage brake shoes against the wheel treads. Compressed air is maintained in the main air reservoirs which are replenished by the main air-compressor. In a long train, the air pressure at various locations in the system will not be exactly equal during application or release of the brakes because of the time required for air to flow long distances through the air lines.

As a result of the time delay for air-pressure to be released after the command for brake release is given by the engineer, one or more of the air brakes on a locomotive wheel can become locked, causing flat spots to be developed on the affected wheel treads . If these flat spots are severe, the wheels must be removed, and turned down by machining or replaced. It is therefore a part of the present invention to include the option of an air-actuated brake release system that can rapidly unlock the brakes on a wheel.

In the present invention, the brake shoes are designed as shown in Figure 12 so that air pressure may be applied to the brake shoe to force it to unlock. Figure 12 shows a schematic view of a possible brake release configuration. Compressed air is fed via an air line 12002 a plenum 12001. The plenum 12001 is formed inside the brake shoe housing 12003 and on the rear side of the brake show 12004. When activated, the brake release system operates by forcing high pressure air through holes 12006 installed in and passing through the brake shoe 12004. This high pressure air is forced between the brake shoe

friction surface 12007 and the braking surface of the wheel 12008, as indicated by arrows 12005, to effect immediate release of the brake shoe 12004 from the wheel 12008. The diameter and location of the holes 12006 are designed so that the air pressure applied between the brake shoe 12004 and the wheel braking surface 12008 exerts a substantially greater force to disengage the brake shoe 12004 than the force exerted by the air-brake cylinder 12009 which is engaging the brake shoe 12004. The release force is preferably between about 10% and 30% greater than the applied braking force. The pressurized air in the brake release plenum 12001 is applied on command by control valves 12010 which may be positioned as shown in Figure 12. The pressure in the air-actuated brake release system may be the same or higher than the air pressure in the brake system. Developing a higher pressure locally can be accomplished by any number of well-known means such as, for example, a cylinder with a variable area piston. The above air-brake release system may be installed using either a tread brake or disc brake configuration.

Although not incorporated in the current embodiment, regenerative braking can be incorporated into the locomotive system, especially for locomotives operating at speeds greater than approximately 50 km/hr. If incorporated, regenerative braking systems would be installed using individual circuits associated with each axle such as is being done by applying individual chopper circuits to each axle in the current preferred embodiment.

When each drive axle on the locomotive has its own chopper circuit, the power to the axle whose wheels are detected to be non-synchronously slipping, can be reduced in until the slipping is eliminated. This individual power control to each drive axle is a primary feature of the present invention. As will be discussed in more detail below, the traction motor electrical current and temperature and the axle rotational speed and temperature can be individually monitored and controlled by a computer monitoring system.

The logic controller is divided into three elements. These are:

(a) control of the power to the traction motors;

(b) control of the charging unit that charges the main energy storage apparatus; and

(c) control of the wheel braking function.

The main power control logic is discussed below with reference to flow diagram of Figure 13.

1. To begin the cycle, the engineer gives total tractive power command 13001 (specifies total power requested)

2. Measure battery volts or the state of charge of the battery or both 13002 to determine if charging generator needs to be on or off

a. when the charging generator is on 13003

i. indicate a warning 13031 when the battery voltage or state of charge or both are below the lower set point and leave the charger on 13004

ii. take no action when the battery voltage or state of charge or both are in the normal range between the upper and lower set points 13005

iii. shut the charging generator off when the battery voltage or state of charge or both are above upper set point 13006

b. when the charging generator is off 13007

i. turn on the generator when the battery voltage or state of charge or both are below upper set point 13008.

ii. leave the generator off when the battery voltage or state of charge or both are above the upper set point 13009

3. Apply required amount of power to all DC traction motors by phasing power output to each DC traction motor according to predetermined algorithm 13010

4. Measure average battery output volts and current to determine battery output power and state of charge 13011. When the battery output power or state of charge is below its lower set point, indicate a warning on the warning screen 13012. Otherwise indicate the operational battery condition on the battery monitor and battery status screens 13013.

5. Loop through all axles with DC traction motors. Do this preferably simultaneously or less preferably in sequence. For each DC traction motor (such as 13014 for example):

a. sense rotational speed (locked, normal or slip) 13015

i. when the brakes are not applied and any wheels are locked 13016, apply air release to the locked wheels 13017

(1) take no further action when brake release is confirmed

(2) when brake release is not confirmed, reapply air release and indicate a warning

ii. take no action when no wheel slippage and no wheels locked 13019

iii. when a wheel is indicated to be slipping 13020, reduce the power to the axle by a specified amount 13021

(1) if the wheel continues to slip, reduce power again, and continue to do so in prescribe increments until slipping stops 13022

(2) take no action when slipping is not occurring

b. measure axle traction motor current 13023

c. adjust power as required by modifying power algorithm 13024

6. To end the cycle, optionally measure all motor, wheel and brake temperatures and adjust algorithms 13025. As will be appreciated, the various set points for controlling the prime energy source, the conversion apparatus, the energy storage units, the chopper circuits and the brake release systems may be somewhat temperature sensitive and this sensitivity can be accounted for by algorithms that reflect known change in set points as a function of temperature.

The charging unit control logic is discussed below in further detail with reference to flow diagram of Figure 14a and 14b. This logic applies when the charging generator is on. There are at least two methods for controlling the charging power so that the alternator presents a constant load to the prime energy source.

One method is to control the charging unit by monitoring engine rotary speed (RPMs). With reference to Figure 14a:

1. Begin the cycle by monitoring the engine (prime energy source) revolutions per minute (RPMs) 14001

a. take no action when the RPMs are within the range set for maximum fuel efficiency 14002

b. when the RPMs are below the lower set point for RPMs, reduce the excitation current to the alternator until the RPMs increase to within their set range for maximum fuel efficiency 14003

c. when the RPMs are above the upper point of RPMs, increase the excitation current to the alternator until the RPMs decrease to within their set range for maximum fuel efficiency 14004

2. End the cycle by repeating the monitoring process

The second method is to control the charging unit by monitoring DC charging power. With reference to Figure 14b:

1. Begin the cycle by monitoring the engine (prime energy source) revolutions per minute (RPMs) 14011

2. Monitor the DC output volts and current of the charging system 14012. This determines output charging power (volts x amperes = watts).

a. take no action when the output power is within the range set for maximum fuel efficiency 14013

b. when the output power is below the lower set point of output power, increase the excitation current to the alternator until the output power increases to within its set range for constant load presented to the prime energy source so that the fuel efficiency can be maintained at or close to its maximum 14014

c. when the output power is above the upper set point of output power, reduce the excitation current to the alternator until the output power decreases to within its set range for constant load presented to the prime energy source 14015

3. Monitor the engine rpms to ensure that they are within the set operating range 14016

a. when the RPMs are within the range set for maximum fuel efficiency, take no action 14017

b. when the RPMs are below the lower set range of RPMs, reduce the excitation current to the alternator until the RPMs increase to within their set range for maximum fuel efficiency 14018

c. when the RPMs are above the upper set range of RPMs, increase the excitation current to the alternator until the RPMs decrease to within their set range for maximum fuel efficiency 14019

4. End the cycle by repeating the monitoring process (steps 14011, *et seq.)*

Yet another method for monitoring engine RPMs is to measure the power frequency of the generator conversion apparatus. The logic flow using this method is identical to that of Figure 14b with "generator power output" replaced by "generator power frequency".

The control logic for the braking system is discussed below in further detail with reference to flow diagram of Figure 15a and 15b. Figure 15a applies when the brakes are applied or activated while Figure 15b applies when the brakes are released or deactivated.

With reference to Figure 15a for brakes on:

1. To begin the cycle, the engineer gives the command to apply the brakes 15001:

2. The true ground speed of the locomotive is determined 15090 by a doppler radar system or other independent motion detector in the locomotive. This is necessary if there is synchronous wheel slip or synchronous wheel locking. In either case, the axle rotary speed sensors would not correctly indicate locomotive ground speed:

3. Loop through all axles with air brake systems. Do this preferably simultaneously or less preferably in sequence. For each axle (such as 15002 for example):

a. sense rotational speed (locked, normal braking, no braking) 15003

i. when the brakes are on and the wheels are indicated to be locked, apply air release 15004

(1) when wheel release is confirmed, take no further action 15005

(2) when wheel release is not confirmed, reapply air release and indicate a warning 15006

ii. when braking is indicated to be normal, take no further action 15007

iii when no braking is sensed, indicate a warning 15020

4. End the cycle by optionally measuring all temperatures 15008.With reference to Figure 15b for brakes off:

1. To begin the cycle, the engineer gives the command to release the brakes 15011:

2. The true ground speed of the locomotive is determined 15091 by a doppler radar system or other independent motion detector in the locomotive:

3. Loop through all axles with air brake systems. Do this preferably simultaneously or less preferably in sequence. For each axle (such as 15012 for example):

a. sense axle rotational speed (locked, normal braking, brakes released) 15013

i. apply air release when brakes are on or the wheels are locked 15014

(1) continue when wheel release is confirmed 15015

(2) when release is not confirmed, reapply air release and indicate a warning 15016

ii. take no further action when braking is indicated to be off 15017

4. To end the cycle, optionally measure brake temperatures 15018

In operation, the PLC determines the power requirement for each motor at each time interval based on inputs from the input device, ramping, derate evaluation logic and detection scaling. Based on such inputs the PLC calculates the necessary pulse width for each motor. The selected pulse widths are then provided to the switch drives which sequentially provide the desired pulse widths of power to the DC motors. When the locomotive is starting for example, a high voltage difference exists between the battery and the motor so a high current can be applied to the motor, which only requires a short pulse duration to meet the power requirement specified. This makes available the full supply voltage for starting in either direction. As the motor speed increases, a back voltage is created which reduces the effective voltage or voltage difference between tho battery and the motor, thus necessitating a longer pulse to achieve the same power. If wheel slippage is detected, power can be shut off or reduced appropriately to the relevant motor.

As will be appreciated, the control system for the various components of the locomotive requires a Graphical User Interface display ("GUI") to provide a user interface for viewing the various monitored parameters and the operational states of the various components and providing operational commands to the various components. This GUI is preferably implemented using a series of related display screens which are configured to receive touch screen commands. This system of screens allows the operator and maintenance crew to monitor and control, for example, the state of the charging generator, the battery pack, the individual drive axles and other functions.

The flow chart shown in Figure 16 shows an example of a touch screen system. Not shown are examples of an air brake system monitor screen and individual axle brake status

screens which can be included in the screen system of the present invention. The individual screens shown in flow chart of Figure 16 are a Main Menu Screen 16001 which controls a number of secondary screens. The secondary (or child) screens include: a Battery Monitor Screen 16002; a Battery Status Screen 16003; a Traction Motor Summary Screen 16004; a Warnings Screen 16005; a Control Tools Screen 16006; and a Derate and Shutdown Screen 16007. The Traction Motor Summary Screen 16004 controls individual Traction Motor Screens 16011, the number of Traction Motor Screens 16011 being equal to the number of drive axles on the locomotive. The individual Traction Motor Screens 16011 are therefore grandchildren of the Main Menu Screen 16001 and children of the Traction Motor Summary Screen 16004. The Control Tools Screen 16006 controls three informational screens which include: an Alarm History Screen 16021; a Digital Input Monitor Screen 16022; and an Output Monitor Screen 16023. The informational screens 16021, 16022 and 16023 are therefore grandchildren of the Main Menu Screen 16001 and children of the Control Tools Screen 16006.

As shown in Figure 17, the Main Menu Screen accesses the following secondary screens:

(a) the Traction Motor Summary Screen 17001 (shown in Figure 18);

(b) the individual Traction Motor Screens 17002 (shown in Figure 19);

(c) the Battery Monitor Screen 17003 (shown in Figure 21);

(d) the Battery Status Screen 17004 (shown in Figure 20);

(e) the Control Tools Screen 17005 (shown in Figure 22);

(f) the Warnings Screen 17006 (shown in Figure 26); and

(g) the Derate and Shutdown Screen 17007 (shown in Figure 27).

In addition, several functions are monitored and controlled from the Main Menu Screen. The functions monitored include:

(a) the locomotive status 17010, which reports on the state of the locomotive, including for example: throttle positions; battery and other electrical conditions; forward, neutral or reverse status; wheel slip;

(b) the charger status 17011, which reports on the state of the charger including for example: charger electrical conditions; temperatures; and status such as running or shutting down;

(c) the locomotive speed 17012, which displays the speed in miles per hour (mph) or other units such, as for example, kilometers per hour (kph);

(d) the throttle notch position 17013, which displays the throttle notch position (from 1 to 8) set manually by the locomotive engineer;

(e) the battery pack voltage 17014, which displays the voltage at the output terminals of the battery pack;

(f) a traction motor status field 17015, with a change in field color indicating that there is a change in status of one or more of the DC traction motors;

(g) a warning field 17016, with change in field color indicating that there is a change in status of one or more of the system warnings; and

(h) a derate or shutdown field 17017, with a change in field color indicating that there is a change in status of derate (going to or remaining in idle) or shutdown (emergency locomotive shutdown).

The functions controlled include a charger manual control 17018, with this button being used to manually start and stop the battery charging generator.

A child screen off of the Main Menu Screen is the Traction Motor Summary Screen depicted in Figure 18 which accesses the individual Traction Motor Screens 18001. The Traction Motor Summary Screen shows, for each traction motor 18002, the position of the various contactors 18003, the current going through each traction motor 18004, the reverser status 18005, the ground fault conditions 18006 and the wheel slip indicator 21007.

The Traction Motor Summary Screen also allows the operator to read and select instantaneous or average current reading 18008 from any of the traction motors. The Traction Motor Summary Screen allows the operator to go back to the Main Menu Screen 18009 or to the Warnings Screen 18010 or to any of the Traction Motor Screens 18002.

A typical Traction Motor Screen, shown in Figure 19, provides more detail about the status of each traction motor including contactor status 19001, motor status 19002, reverser status 19003, wheel slip status 19004 and motor current 19005. This screen also allows the operator to open contactors 19011, monitor the motor cutout status 19012, cut out the traction motor 19013 and de-energize the reverser 19014. Field 19021 of each of the Traction Motor Screens allows the operator to go back to the main menu screen.

The Battery Status Screen, shown in Figure 20, displays details about the electrical state of the energy storage unit (*e.g.*, battery ) and the status of the mechanical-to-electrical conversion device (*e.g.*, charging generator ). The displayed fields include:

(a) B-Contactor Status 20001, which reports whether the Battery contactors are open or closed;

(b) Battery Power 20002, which displays the current power being delivered by the energy storage unit to the drive system;

(c) Battery voltage 20030

(d) Battery current 20031

(e) Battery Energy Delivered to Date 20003, which provides the total amount of kWh the energy storage unit has delivered to the drive system;

(f) Battery State of Charge 20004, which depicts, in a bar graph format, the state of charge of the energy storage unit by measuring the amp-hours in and the amp-hours out;

(g) Charger Status 20005, which reports what the mechanical-to-electrical conversion device (*e.g.*, charging generator ) is currently doing such as, for example, mode of operation (warming up etc); current charge, load charge, cooling status;

(h) Charger Power 20006, which reports the power being produced by the mechanical-to-electrical conversion device (*e.g.*, charging generator ) for charging the energy storage unit. When the conversion apparatus is not running, this field will provide a negative value to reflect the power draw out of the storage unit by the auxiliary systems; and

(i) Charger Energy Produced to Date 20006, which reports the power that the conversion device has produced for replacing the energy drawn from the energy storage unit by the drive system but does not include the draw of the auxiliaries.

(j) Charger frequency 20032

(k) Charger current 20033

In addition, the Battery Status Screen allows control of the mechanical-to-electrical conversion device (*e.g.*, charging generator ) through:

(a) the Charger Manual Control Button 20011, which can be used to manually start and stop the conversion device; and

(b) the Charger Disabler Button 20012, which allows the operator to disable the charge scheme for the conversion device, preventing it from starting automatically or through the manual charger control button 20011.

The Battery Status Screen is a child of the Main Menu Screen, is accessed from the the Main Menu Screen and, using field 20013, allows the operator to return to the Main Menu Screen.

The Battery Monitor Screen, shown in Figure 21, relays the signals from the battery monitoring system to the operator. The three squares 21001 on the left correspond to the three left-most LEDs in the battery monitoring system box, which correspond to temperature faults in the energy storage unit. The field 21003 directly below the three squares 21001 provide more detail about the fault detected. The two squares 21004 on the right correspond to the right most LEDs in the battery monitoring system box, which correspond to voltage faults. The field 21006 below the two squares 21004 give more detail about the fault condition detected. This screen is a child of the Main Menu Screen, is accessed from the Main Menu Screen and, using field 21008, allows the operator to return to the Main Menu Screen.

The Control Tools Screen, shown in Figure 22, is a child of the Main Menu Screen and, in turn, accesses the various informational screens, such as the Alarm History Screen of Figure 31, the Digital Input Monitor Screen of Figure 32 and the Output Monitor Screen of Figure 33.

The Control Tools Screen shows the following fields:

(a) a 600 V ground fault indicator 22001;

(b) ground leakages 22002 detected on each traction motor;

(c) battery power set point 22003;

(d) battery current 22004;

(e) horsepower being developed 22005; and

(f) traction motor leakage detected during last test 22006.

The Control Tools Screen also has a ground fault detection control button 22011, which turns color when a ground fault has been detected. Pushing the ground fault detection control button 22011 starts a ground fault detection process. This screen is a child of the Main Menu Screen, is accessed from the Main Menu Screen and, using field 22012, allows

the operator to return to the Main Menu Screen. This screen allows the operator to access the Alarm History Screen via field 22013, the Digital Input Monitor Screen via field 22014 and the Output Monitor Screen via field 22015.

The Alarms History Screen, shown in Figure 23, keeps a record of all of the alarms and warnings 23001 reported on the touch-screen. The Alarm History Screen is a child of the Control Tools Screen and allows the operator to go back to the Main Menu Screen via field 23002, to the Warnings Screen via field 23012 or to the Derate and Shutdown Screen via field 23013. The Alarm History Screen also has a button 23014 that allows the operator to clear the list 23001 of past alarms and warnings.

A Digital Input Monitor Screen, shown in Figure 24, indicates the various inputs to the control computer monitors and shows the status of that input. If there is no signal seen by the control computer, the square 24001 will be black, and if a signal is present, square 31001 will be green. The various input boards are given an address 24002, such, as for example, "I" means input board. The first number 24003 designates which board (3, 4, or 5), and the second number 24004 designates which tab on the board (0 to 15). This screen also has a button 24011to reset the pulse width board signal. The Digital Input Monitor Screen allows the operator to go back to the Main Menu Screen via field 24012, the Control Tools Screen via field 24013, or to the Output Monitor Screen via field 24014.

An Output Monitor Screen, shown in Figure 25, shows the various output the control computer uses, and the status of the outputs. If there is no signal, the square 25001 will be blue, if there is a signal going out, then the square 25001 is red. The Output Monitor Screen also has an output control button 25011, which allows the operator to override the logic of the control computer and to enable any of the outputs manually. The Output Monitor Screen is a child of the Control Tools Screen and allows the operator to go back to the Control Tools Screen via field 25012 or to the Digital Input Monitor Screen via field 25013.

A Warnings Screen, shown in Figure 26, displays minor alarms that have been detected.

The warnings contains information on:

(a) an improper reverser condition or mismatch field 26001;

(b) a throttle mismatch field 26002;

(c) a B-contactor mismatches field 26003 and P-contactor mismatches field 26004;

(d) a high or low current warnings field 26005 indicating an unacceptably high or low current on any of the traction motors 26006;

(e) a low voltage warning field 26007 indicating a low voltage on the energy storage unit;

(f) a ground leakage field 26008; and

(g) a high temperature warning field 26009 indicating an unacceptably high temperature on the any of the traction motors, in the energy storage unit, or on the chopper board heat sinks.

The Warnings Screen is a child of the Main Menu Screen and allows the operator to go back to the Main Menu Screen via field 26011, the Battery Warning Screen via field 26012 or the Derate and Shutdown Screen via field 26013.

A Derate and Shutdown Screen, shown in Figure 27, displays alarms that caused the locomotive to unload and/or prevent it from loading to full power. Some functions flagged on this screen may be controlled manually and some are controlled automatically. An example of the latter is an automatic reduction in power to a motor whose IGBT has exceeded its preset temperature limit. This screen includes information on:

(a) an off /shutdown alarms field 27001 indicating an alarm that caused the locomotive to do an emergency shutdown where the B-Contactors opened up;

(b) an emergency fuel shutoff indicator button 27002, a stop command button 27003, a pneumatic control switch button 27004, an emergency sanding switch button 27005, an isolation switch condition button 27006, an engine run switch indicator 27007, a 600 VDC ground fault detection button 27008, at least one of the electrical cabinet doors has been opened indicator 27009, excessive battery current detected 27010, low battery voltage indicator 27011, thermal fuse on the filter board short indicator 27012, and excessive locomotive speed indicator 27013;

(c) an idle derate alarm field 27014 indicating an alarm that have caused the locomotive to go to or remain in idle, but the B-Contactors have remained closed. This includes conditions where the generator field switch is off, one or more P-Contactor has not aligned correctly, or the battery current is being detected when it should not be;

(d) a traction motor high current derate field 27015 indicating that the locomotive is not developing full power because of high current in the traction motors;

(e) an RVR MM Cut-Out field 27016 indicating that the locomotive is not developing full power because a reverser will not align in the given direction, or full power is not being developed because a traction motor was manually cut out; and

(f) a ground derate field 27016 indicating that the locomotive will not load because there is a 600 V ground fault condition, or the locomotive will not load because it is in the process of a ground fault detection test.

The Derate and Shutdown Screen also has a button 27021 that can be pushed to acknowledge an alarm and clear it from the system. The Derate and Shutdown Screen is a child of the Main Menu Screen and allows the operator to go back to the Main Menu Screen via field 27022.

A number of variations and modifications of the invention can be used. As will be appreciated, it would be possible to provide for some features of the invention without providing others. For example in one alternative embodiment, the various inventive features are applied to vehicles other than locomotives, such as cars, railroad cars, and trucks. The control logic set forth above may be implemented as a logic circuit, software, or as a combination of the two.

The present invention, in various embodiments, includes components, methods, processes, systems and/or apparatus substantially as depicted and described herein, including various embodiments, subcombinations, and subsets thereof. Those of skill in the art will understand how to make and use the present invention after understanding the present disclosure. The present invention, in various embodiments, includes providing devices and processes in the absence of items not depicted and/or described herein or in various embodiments hereof, including in the absence of such items as may have been used in previous devices or processes, for example for improving performance, achieving ease and\or reducing cost of implementation.

The foregoing discussion of the invention has been presented for purposes of illustration and description. The foregoing is not intended to limit the invention to the form or forms disclosed herein. In the foregoing Detailed Description for example, various features of the invention are grouped together in one or more embodiments for the purpose

of streamlining the disclosure. This method of disclosure is not to be interpreted as reflecting an intention that the claimed invention requires more features than are expressly recited in each claim. Rather, as the following claims reflect, inventive aspects lie in less than all features of a single foregoing disclosed embodiment. Thus, the following claims are hereby incorporated into this Detailed Description, with each claim standing on its own as a separate preferred embodiment of the invention.

Moreover though the description of the invention has included description of one or more embodiments and certain variations and modifications, other variations and modifications are within the scope of the invention, e.g. as may be within the skill and knowledge of those in the art, after understanding the present disclosure. It is intended to obtain rights which include alternative embodiments to the extent permitted, including alternate, interchangeable and/or equivalent structures, functions, ranges or steps to those claimed, whether or not such alternate, interchangeable and/or equivalent structures, functions, ranges or steps are disclosed herein, and without intending to publicly dedicate any patentable subject matter.

What is claimed is:

1. A locomotive, comprising:

a plurality of direct current traction motors corresponding to a plurality of axles and a plurality of drive switches; and

a plurality of free-wheeling bypass circuits, each bypass circuit bypassing a corresponding one of the plurality of plurality of drive switches.

2. The locomotive of claim 2, further comprising:

a plurality of chopper circuits corresponding to the plurality of direct current traction motors, each chopper circuit comprising a respective free-wheeling bypass circuit and drive switch in electrical communication with a respective direct current traction motor.

3. The locomotive of claim 2, wherein, in a first mode, at least most of the electrical current passing through the chopper circuit passes through the corresponding free-wheeling bypass circuit and the corresponding traction motor and bypasses the corresponding drive switch and, in a second mode, at least most of the electrical current passing through the chopper circuit passes through the corresponding drive switch and traction motor and bypasses the corresponding free-wheeling bypass circuit.

4. The locomotive of claim 3, wherein, during a selected time interval, a first chopper circuit corresponding to a first traction motor is in the first mode and a second chopper circuit corresponding to a second traction motor is in the second mode.

5. The locomotive of claim 1, wherein each free-wheeling bypass circuit comprises a free-wheeling gate.

6. The locomotive of claim 1, further comprising:

a plurality of filters, each filter corresponding to one of the plurality of direct current traction motors, to absorb electrical voltage transients and smooth current ripples through the traction motors resulting from changes between the driven and free-wheeling modes.

8. A locomotive, comprising:

a plurality of direct current traction motors in communication with a plurality of axles;

a prime energy source;

an energy conversion device, in communication with the prime energy source, to convert the energy output by the prime energy source into direct current electricity ; and

an energy storage device, in communication with the energy conversion device and the plurality of traction motors, to receive and store the direct current electricity, wherein the energy storage device comprises a plurality of capacitors operable to store the stored energy.

9. The locomotive of claim 8 wherein at least most of the stored electricity is stored in the plurality of capacitors.

10. The locomotive of claim 9 further comprising a pulse forming network to convert the output of the plurality of capacitors to a form acceptable to the traction motors.

11. A locomotive, comprising:

a plurality of traction motors in communication with a plurality of axles;

a prime energy source for providing power to the plurality of traction motors; and

a plurality of braking systems operatively engaging a respective one of the plurality of axles, each braking system comprising at least one moveable braking element and a corresponding brake cylinder and a fluid-activated brake release, wherein, when the moveable braking element is locked in position against a braking surface, fluid pressure is applied by the fluid-activated brake release to disengage the locked moveable braking element from the braking surface.

12. The locomotive of claim 11 wherein each moveable braking element comprises a plurality of holes passing therethrough and the fluid-activated brake release forces fluid through the holes and against the braking surface to form a brake release force.

13. The locomotive of claim 12 wherein the force required to unlock a locked moveable braking element is the braking force and the release force is at least about 10% greater than the braking force.

14. A locomotive, comprising:

a plurality of direct current traction motors in communication with a plurality of axles;

a prime energy source;

an energy conversion device, in communication with the prime energy source, to convert the energy output by the prime energy source into direct current electricity;

an energy storage device, in communication with the energy conversion device and the plurality of traction motors, to receive and store the direct current electricity;

a controller operable to control an excitation current to the energy conversion device, wherein at least one of the following statements is true:

(i) when a first predetermined set point is exceeded by a first monitored parameter, the excitation current is increased and, when a second predetermined set point exceeds the first monitored parameter, the excitation current is decreased and wherein the first monitored parameter is revolutions per minute of a mechanical component of the prime energy source and

(ii) when the first predetermined set point is exceeded by a second monitored parameter, the excitation current is decreased and, when the second predetermined set point exceeds the second monitored parameter, the excitation current is increased and wherein the second monitored parameter is the output power of the energy conversion device.

15. The locomotive of claim 14 wherein the first and second predetermined set points are selected to produce at least a desired degree of fuel efficiency for the prime energy source.

16. The locomotive of claim 14 wherein (i) is true.

17. The locomotive of claim 14 wherein (ii) is true.

18. A locomotive, comprising:

a plurality of direct current traction motors in communication with a plurality of axles;

a prime energy source;

an energy conversion device, in communication with the prime energy source, to convert the energy output by the prime energy source into direct current electricity;

an energy storage device, in communication with the energy conversion device and the plurality of traction motors, to receive and store the direct current electricity;

a controller operable to monitor an operational parameter of each of the plurality of axles and/or traction motors, wherein the monitored operational parameter is at least one of revolutions per minute of an axle, an electrical current provided to a traction motor, and a voltage applied to a component of a traction motor.

19. The locomotive of claim 18, further comprising:

a graphical user interface operable to provide the electrical current passing through each of the plurality of direct current traction motors to an operator.

20. The locomotive of claim 18 wherein the controller is further operable to activate an alarm when the electrical current passing through one or more of the direct current traction motors exceeds a predetermined threshold.

21. The locomotive of claim 18 wherein the controller is operable to control each of the plurality of traction motors independently of the other traction motors.

22. The locomotive of claim 18 wherein the controller is operable to decrease power supplied to a first traction motor engaging a first axle without decreasing the power supplied to other traction motors when the revolutions per minute exceed a selected threshold.

23. The locomotive of claim 18 further comprising:

an air brake assembly located on each of the plurality of axles, the air brake assembly comprising one or more brake shoes, an air cylinder, and an fluid-activated brake release.

24. The locomotive of claim 18 wherein, when a first air brake assembly is locked in engagement with a first braking surface on a first axle but a second air brake assembly is not locked into engagement with a second braking surface on a second axle, the controller is operable to activate a first fluid-activated brake release on the first axle without activating a second fluid-activated brake release on the second axle.

25. The locomotive of claim 18 wherein a brake assembly is deemed to be locked when the locomotive is in motion, the air brake assembly is deactivated, and the revolutions per minute on the axle engaging the air brake assembly are at least substantially zero.

26. A locomotive, comprising:

a plurality of direct current traction motors in communication with a plurality of axles;

a prime energy source;

an energy conversion device, in communication with the prime energy source, to convert the energy output by the prime energy source into direct current electricity;

an energy storage device, in communication with the energy conversion device and the plurality of traction motors, to receive and store the direct current electricity;

a user interface operable to receive a command from an operator to control a locomotive speed at a specified velocity; and

a controller operable to control the velocity of the locomotive at or near the specified velocity by performing at least one of the following steps:

(i) maintaining a substantially constant power across each of the plurality of traction motors, the power being related to the specified velocity; and

(ii) maintaining the revolutions per minute of each of the plurality of axles at a rate related to the specified velocity.

27. The locomotive of claim 26 wherein step (i) is performed.

28. The locomotive of claim 26 wherein step (ii) is performed.

29. The locomotive of claim 26 wherein corresponding power applied across at least two of the traction motors are different.

30. The locomotive of claim 26 wherein corresponding revolutions per minute of at least two of the axles are different.

**AMENDED CLAIMS**
[received by the international Bureau on 21 May 2004 (21.05.04), claim 2 amendedd, the claims 31-37 added]

1. A locomotive, comprising:

a plurality of direct current traction motors corresponding to a plurality of axles and a plurality of drive switches; and

a plurality of free-wheeling bypass circuits, each bypass circuit bypassing a corresponding one of the plurality of plurality of drive switches.

2. The locomotive of claim 1, further comprising:

a plurality of chopper circuits corresponding to the plurality of direct current traction motors, each chopper circuit comprising a respective free-wheeling bypass circuit and drive switch in electrical communication with a respective direct current traction motor.

3. The locomotive of claim 2, wherein, in a first mode, at least most of the electrical current passing through the chopper circuit passes through the corresponding free-wheeling bypass circuit and the corresponding traction motor and bypasses the corresponding drive switch and, in a second mode, at least most of the electrical current passing through the chopper circuit passes through the corresponding drive switch and traction motor and bypasses the corresponding free-wheeling bypass circuit.

4. The locomotive of claim 3, wherein, during a selected time interval, a first chopper circuit corresponding to a first traction motor is in the first mode and a second chopper circuit corresponding to a second traction motor is in the second mode.

5. The locomotive of claim 1, wherein each free-wheeling bypass circuit comprises a free-wheeling gate.

6. The locomotive of claim 1, further comprising:

a plurality of filters, each filter corresponding to one of the plurality of direct current traction motors, to absorb electrical voltage transients and smooth current ripples through the traction motors resulting from changes between the driven and free-wheeling modes.

8. A locomotive, comprising:

a plurality of direct current traction motors in communication with a plurality of axles;

a prime energy source;

an energy conversion device, in communication with the prime energy source, to convert the energy output by the prime energy source into direct current electricity ; and

a controller operable to control the velocity of the locomotive at or near the specified velocity by performing at least one of the following steps:

(i) maintaining a substantially constant power across each of the plurality of traction motors, the power being related to the specified velocity; and

(ii) maintaining the revolutions per minute of each of the plurality of axles at a rate related to the specified velocity.

27. The locomotive of claim 26 wherein step (i) is performed.

28. The locomotive of claim 26 wherein step (ii) is performed.

29. The locomotive of claim 26 wherein corresponding power applied across at least two of the traction motors are different.

30. The locomotive of claim 26 wherein corresponding revolutions per minute of at least two of the axles are different.

31. A method for addressing non-synchronous wheel slippage, comprising:

providing a plurality of traction motors, each of the plurality of traction motors being independently coupled to and driving at least one wheel;

detecting an operating characteristic of each of the plurality of traction motors;

determining that the at least one wheel corresponding to a first traction motor is experiencing wheel slippage; and

in response to the determining step, reducing power supplied to the first traction motor for a selected period of time while continuing to provide power in excess of the reduced power to the remaining traction motors.

32. The method of claim 31, wherein the determining step comprises:

determining that the operating characteristic of the first traction motor has a predetermined relationship with an operating characteristic setpoint, wherein the operating characteristic is at least one of a corresponding operating speed of each of the plurality of traction motors and a corresponding electrical current supplied to each of the plurality of traction motors and further comprising:

comparing a detected operating characteristic detected for each of the traction motors to the operating characteristic setpoint and wherein, when the detected operating speed has the predetermined relationship with the operating characteristic setpoint, the at least one wheel of the corresponding traction motor is determined to be experiencing wheel slippage.

33. The method of claim 31, wherein the reducing step is performed until the detected operating characteristic for the first traction motor no longer has the predetermined relationship with the operating characteristic setpoint.

34. A system for addressing non-synchronous wheel slippage, comprising:

a plurality of traction motors, each of the plurality of traction motors being independently coupled to and driving at least one wheel;

a plurality of sensors operable to sense an operating characteristic of each of the plurality of traction motors, wherein each of the sensors corresponds to a traction motor; and

a controller operable to determine that the at least one wheel corresponding to a first traction motor is experiencing wheel slippage and, in response thereto, reduce a level of power supplied to the first traction motor for a selected period of time while continuing to provide levels of power in excess of the reduced power to the remaining traction motors.

35. The system of claim 34, wherein the controller is further operable to determine that the operating characteristic of the first traction motor has a predetermined relationship with a speed set point and wherein the controller is further operable to compare a detected operating characteristic detected for each of the traction motors to the operating characteristic set point and, when the detected operating characteristic exceeds the operating characteristic set point, determine that the at least one wheel of the corresponding traction motor is experiencing wheel slippage.

36. The system of claim 34, wherein the controller is operable to reduce the level of power supplied to the first traction motor until the at least one wheel of the first traction motor is no longer experiencing slippage and wherein the operating characteristic is a corresponding electrical current supplied to each of the traction motors.

37. The system of claim 34, wherein the controller is operable to increase the level of power supplied to the first traction motor when the at least one wheel of the first traction motor has a detected operating speed in excess of the speed set point.

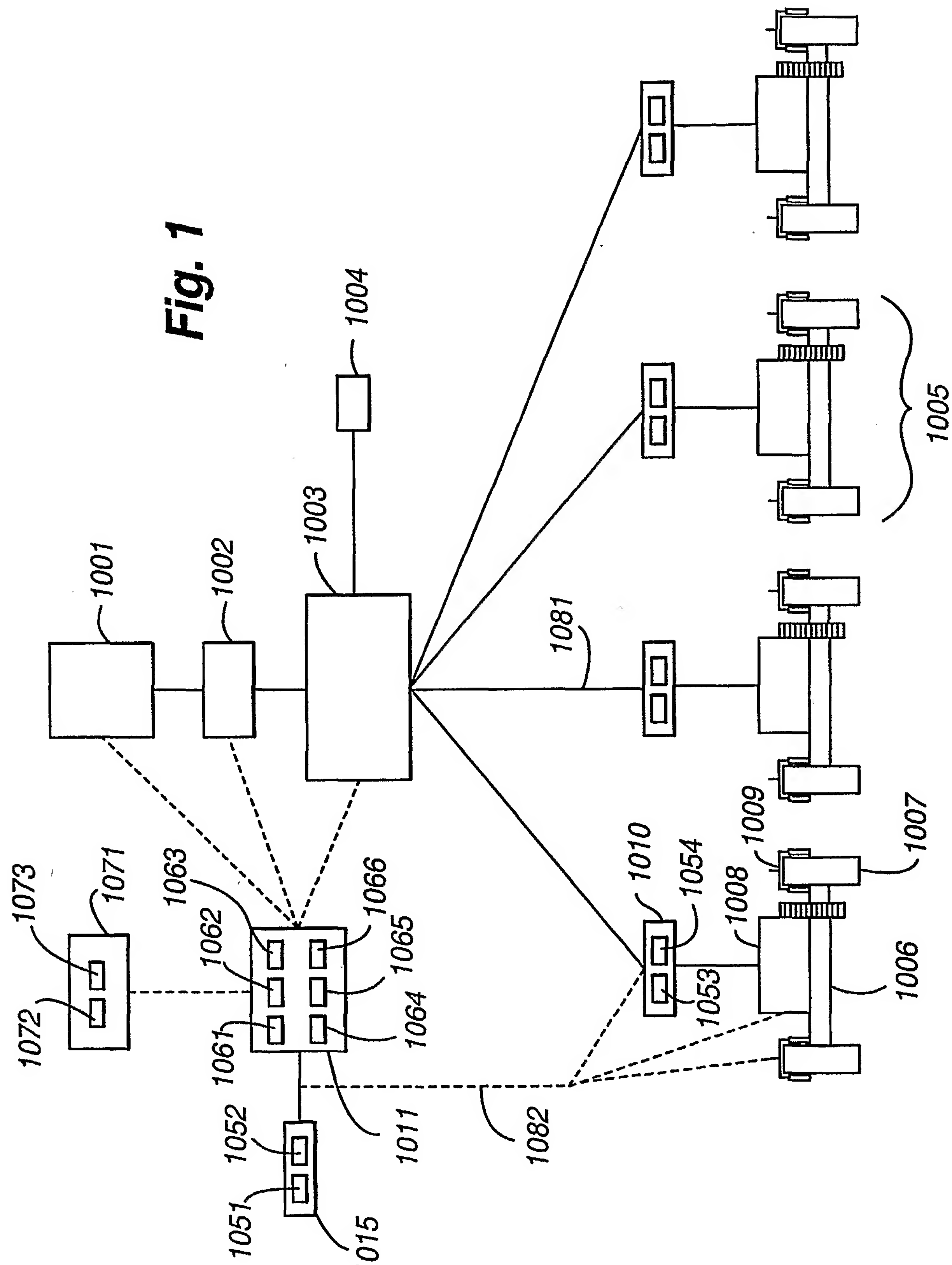
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Fig. 1

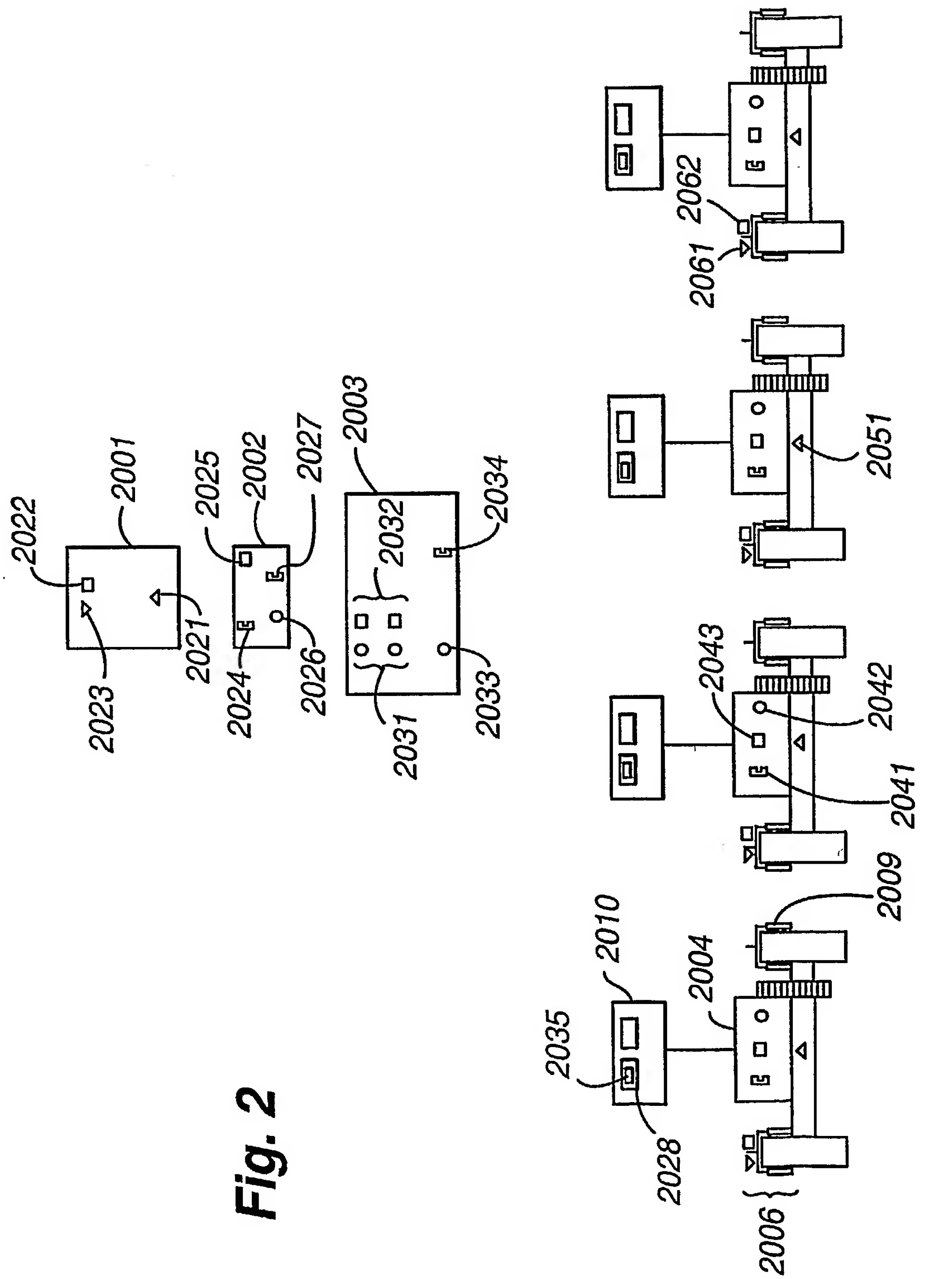
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Fig. 2

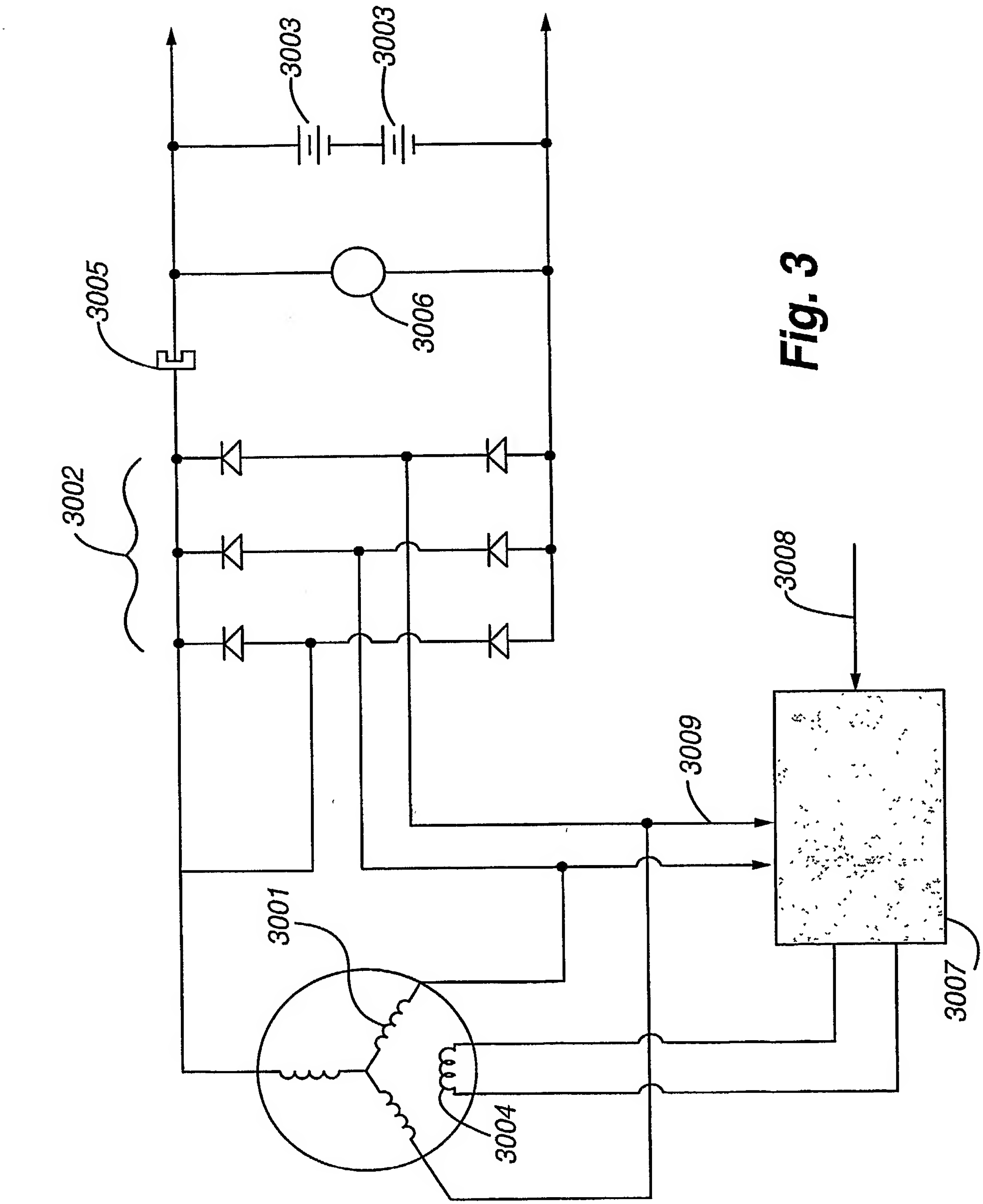
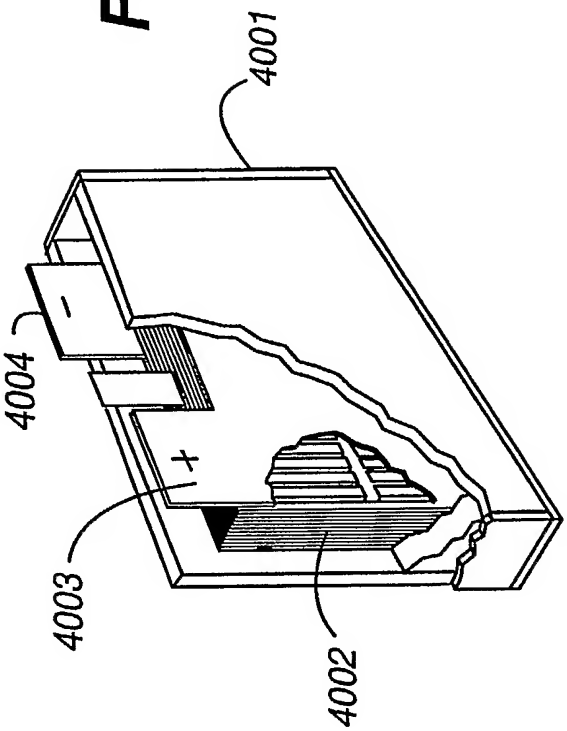



Fig. 3

Fig. 4a



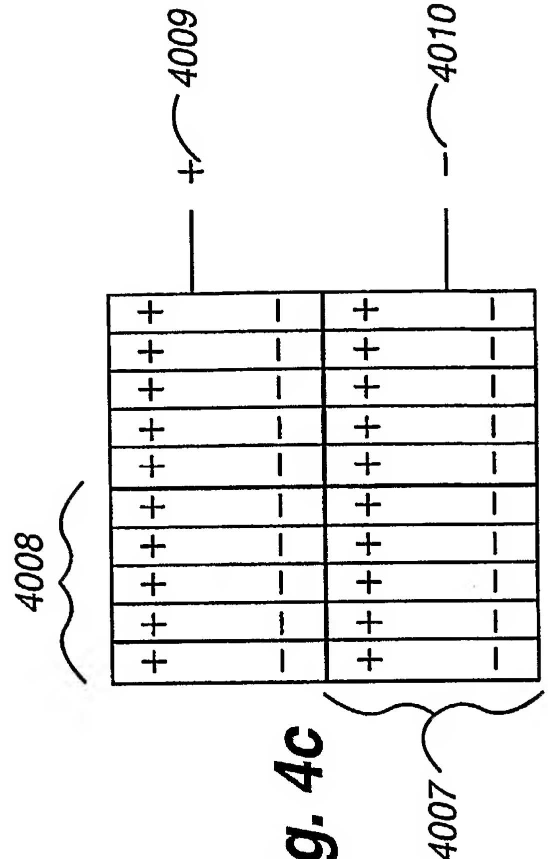




Fig. 4c

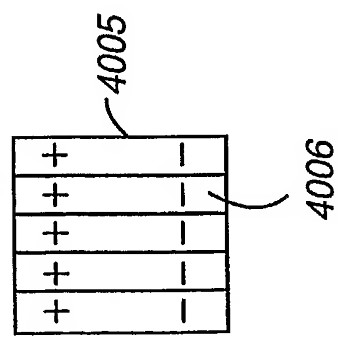



Fig. 4b

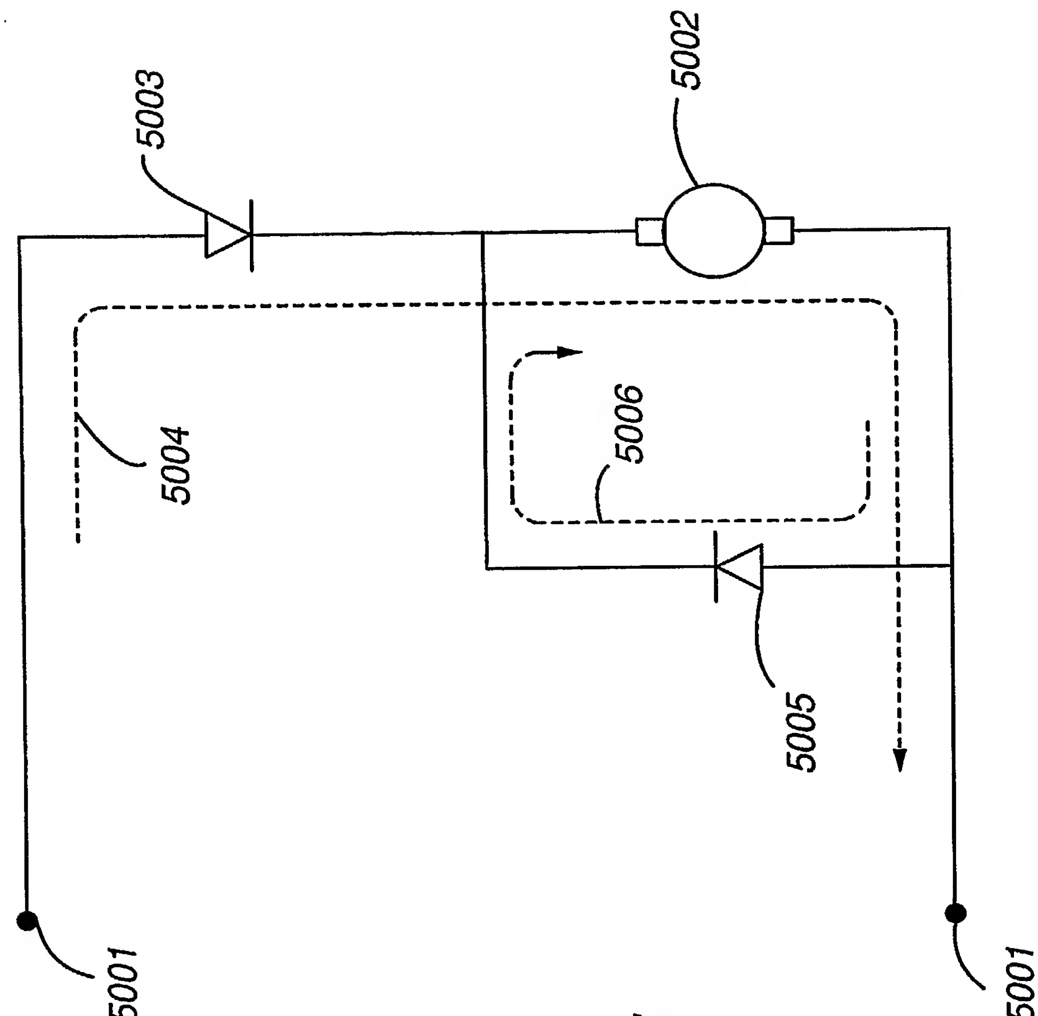



Fig. 5

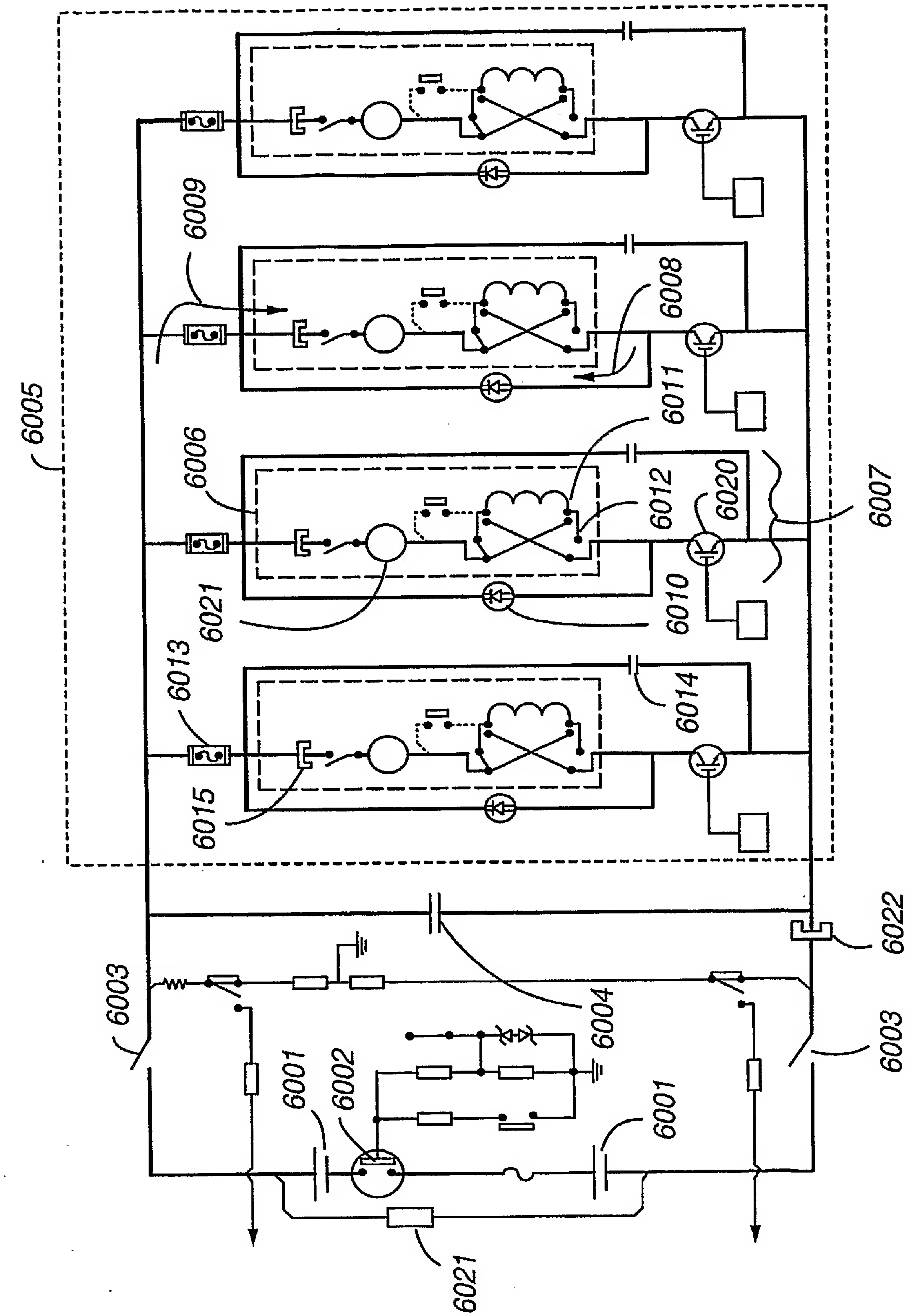

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Fig. 6

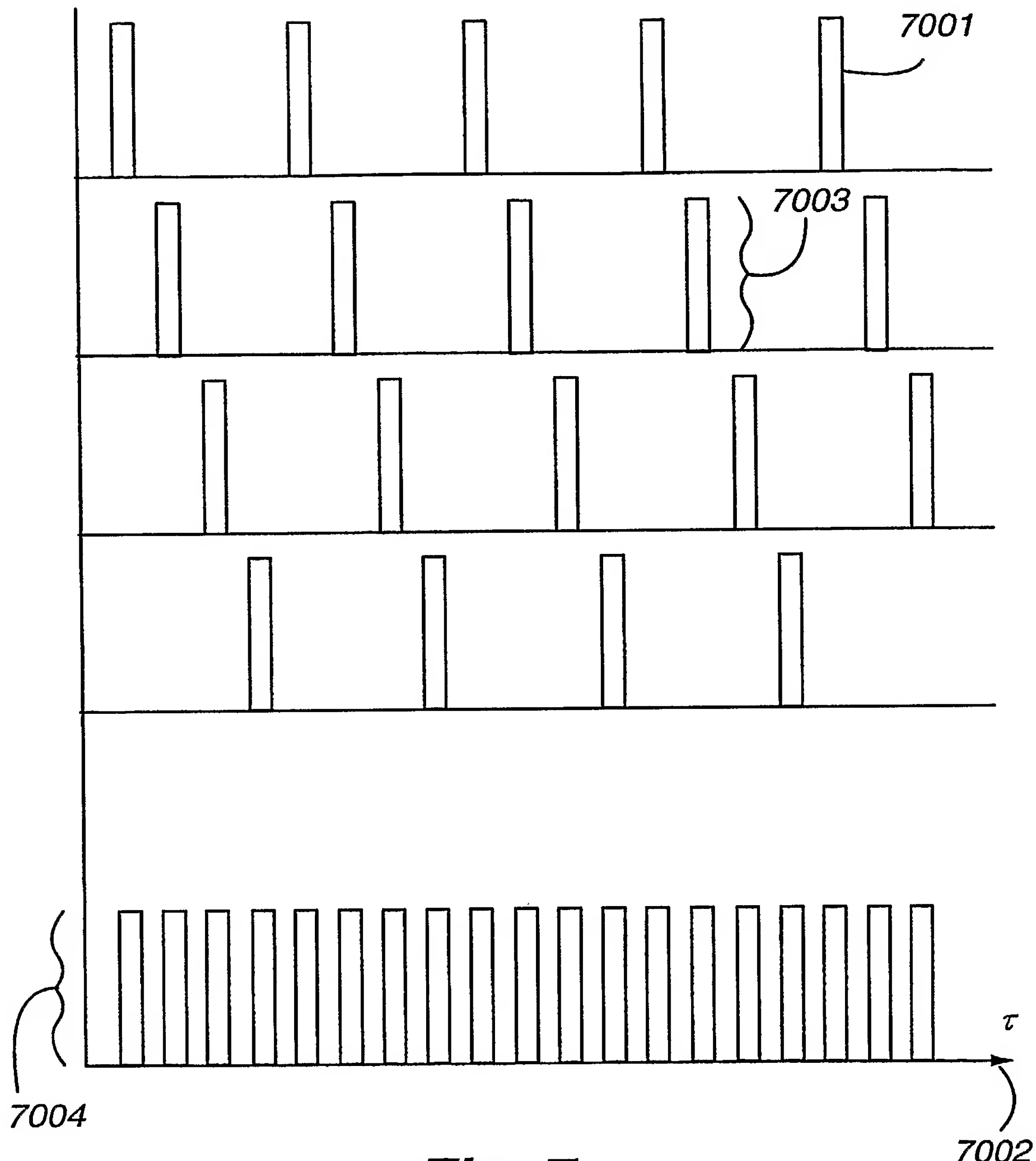


Fig. 7

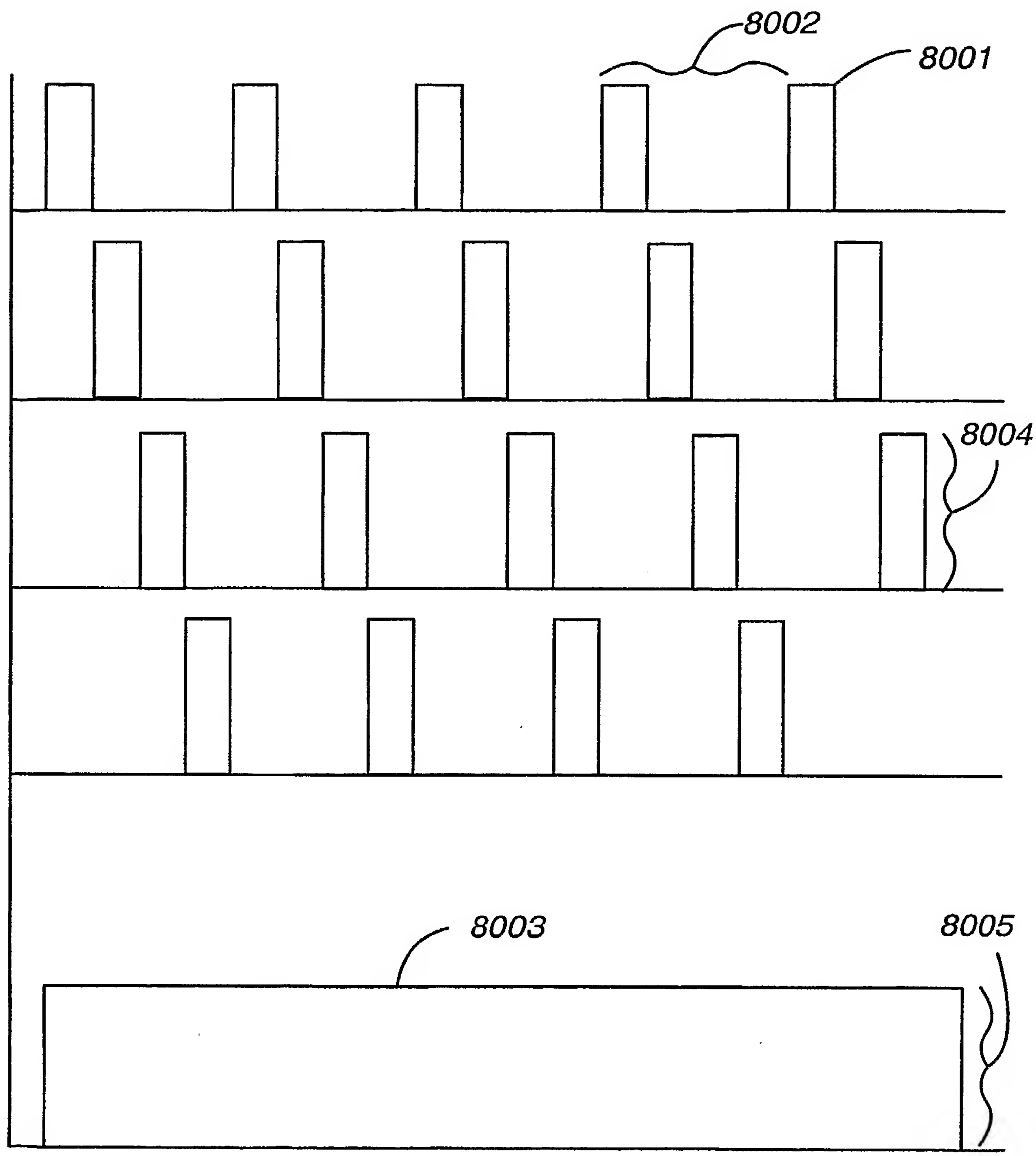


Fig. 8

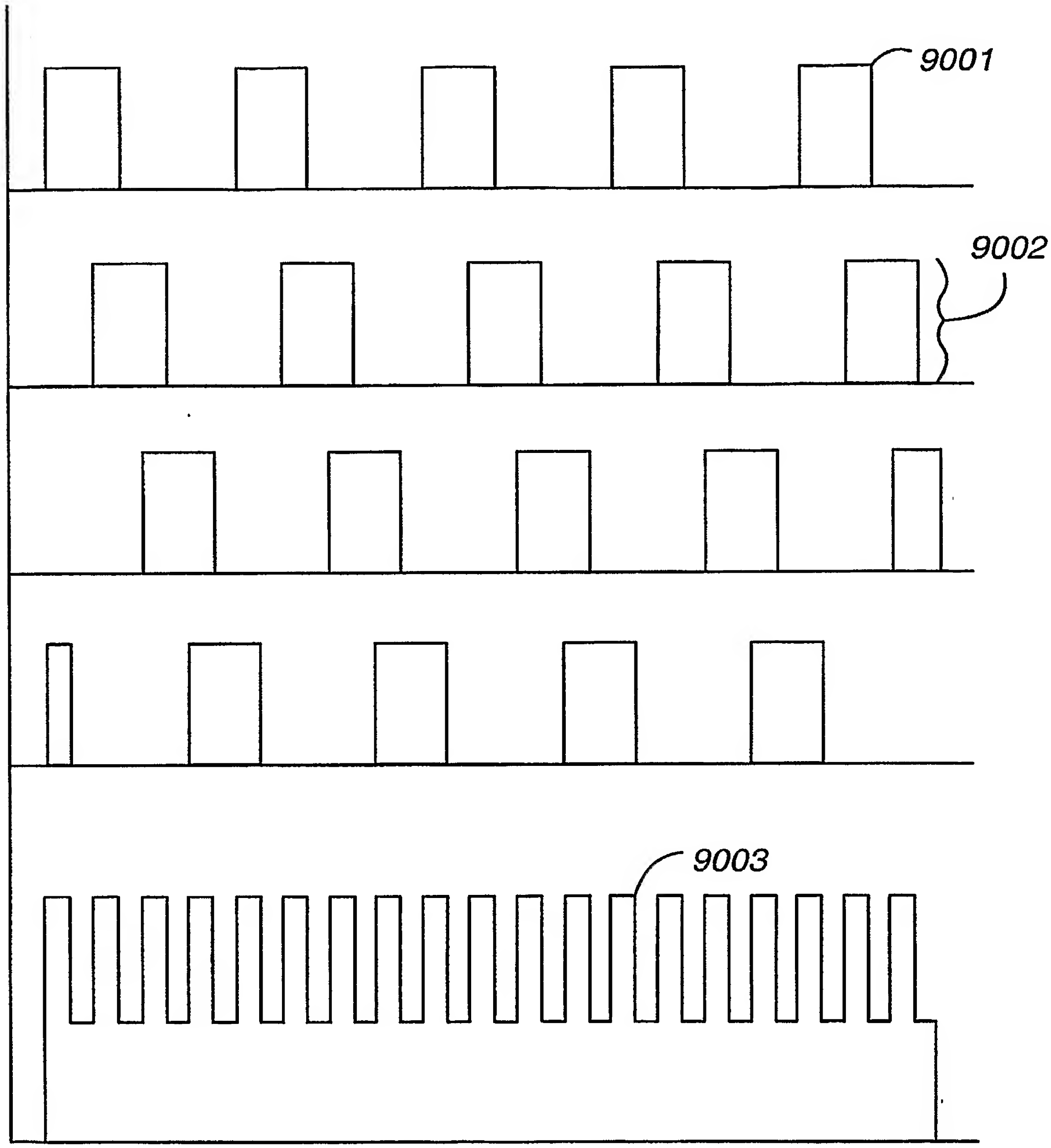


Fig. 9

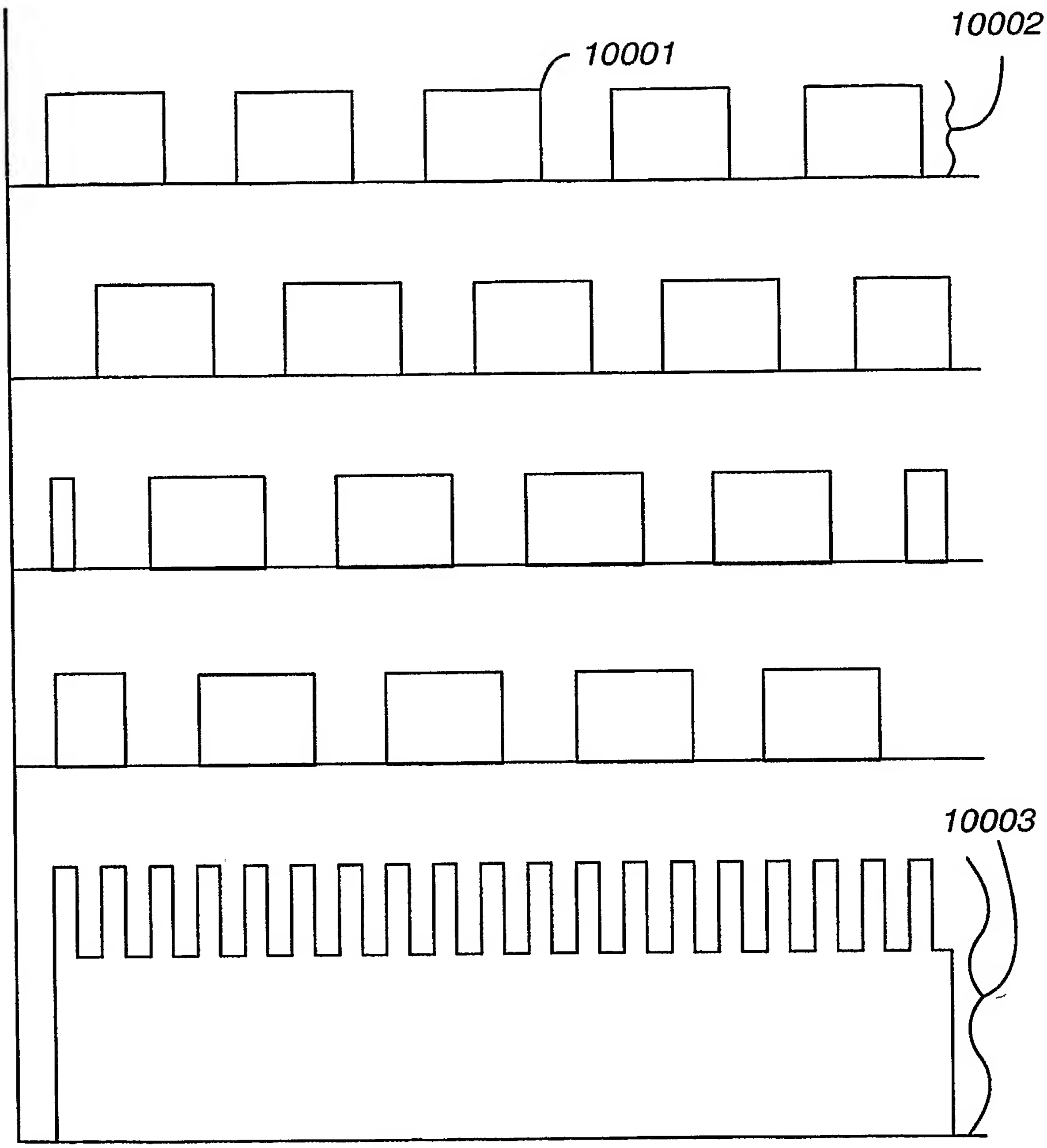


Fig. 10

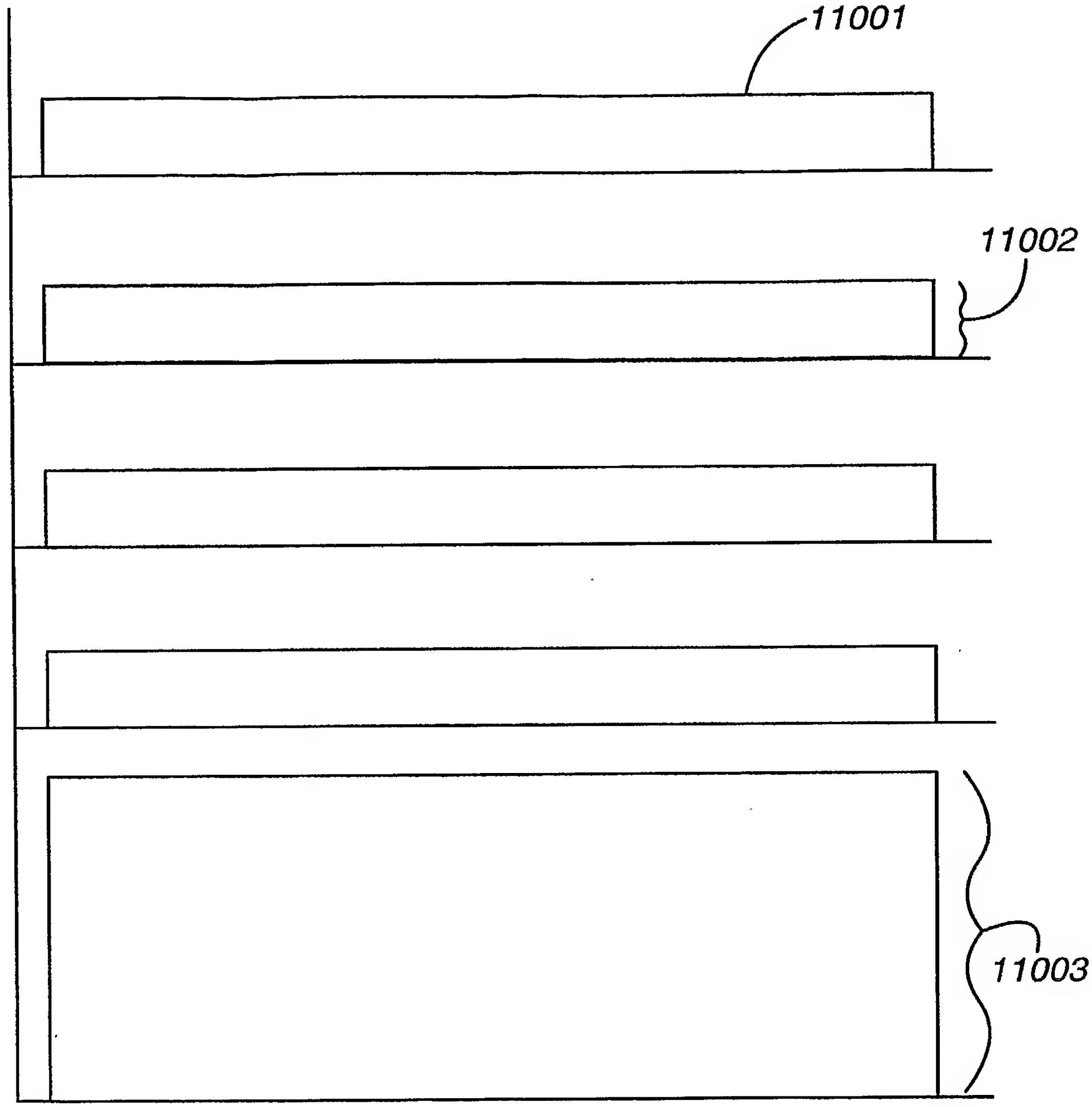


Fig. 11

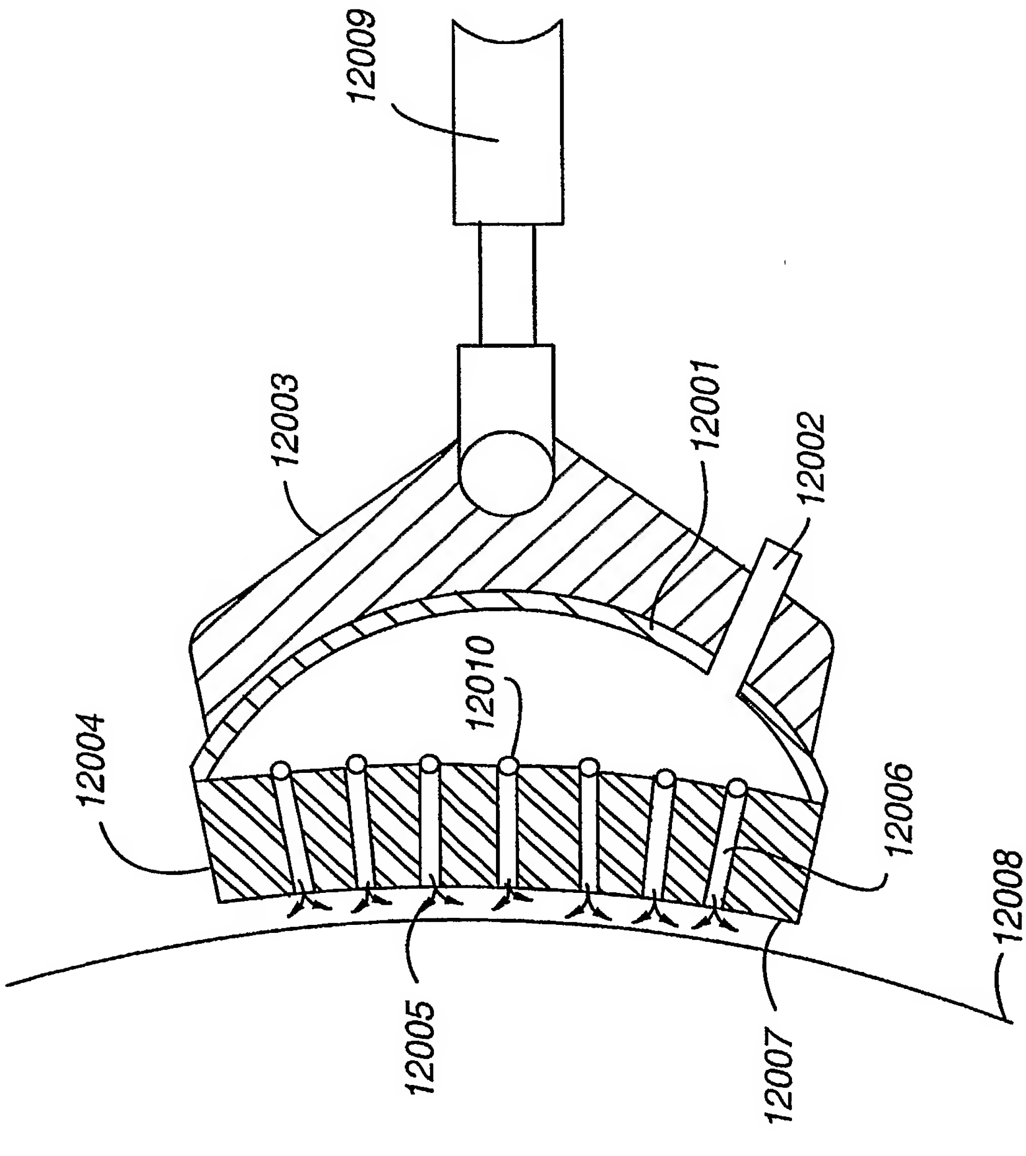
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Fig. 12

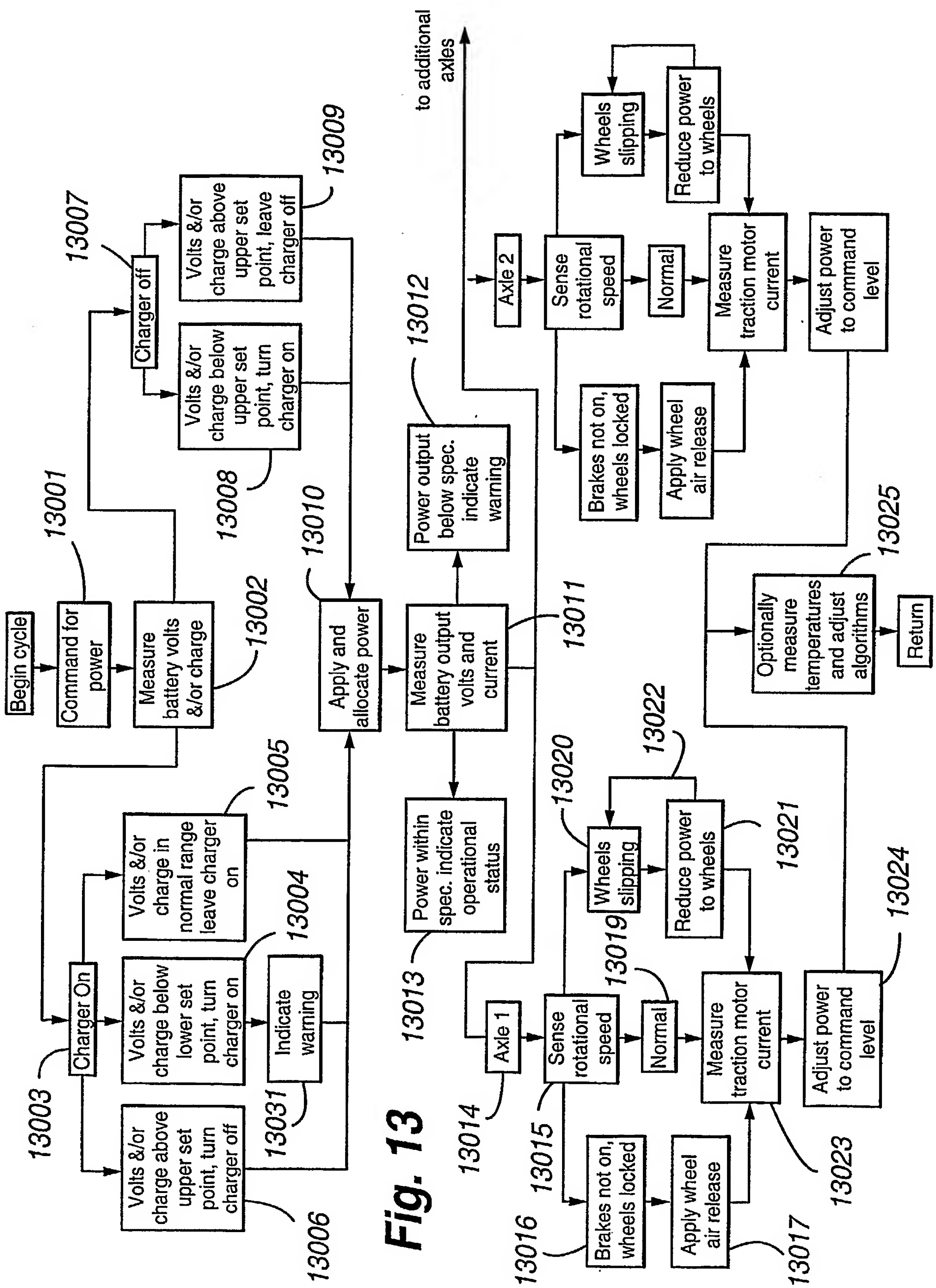

Begin cycle
Command for power
13001
Measure battery volts &/or charge
13002
Charger off
13007
Volts &/or charge below upper set point, turn charger on
13008
Volts &/or charge above upper set point, leave charger off
13009
Charger On
13003
Volts &/or charge above upper set point, turn charger off
13006
Volts &/or charge below lower set point, turn charger on
13004
Indicate warning
13031
Volts &/or charge in normal range leave charger on
13005
Apply and allocate power
13010
Measure battery output volts and current
13011
Power output below spec. indicate warning
13012
Power within spec. indicate operational status
13013
to additional axles
Axle 1
13014
Sense rotational speed
13015
Brakes not on, wheels locked
13016
Apply wheel air release
13017
Normal
13019
Wheels slipping
13020
Reduce power to wheels
13021
13022
Measure traction motor current
13023
Adjust power to command level
13024
Axle 2
Sense rotational speed
Brakes not on, wheels locked
Apply wheel air release
Normal
Wheels slipping
Reduce power to wheels
Measure traction motor current
Adjust power to command level
Optionally measure temperatures and adjust algorithms
13025
Return

Fig. 13

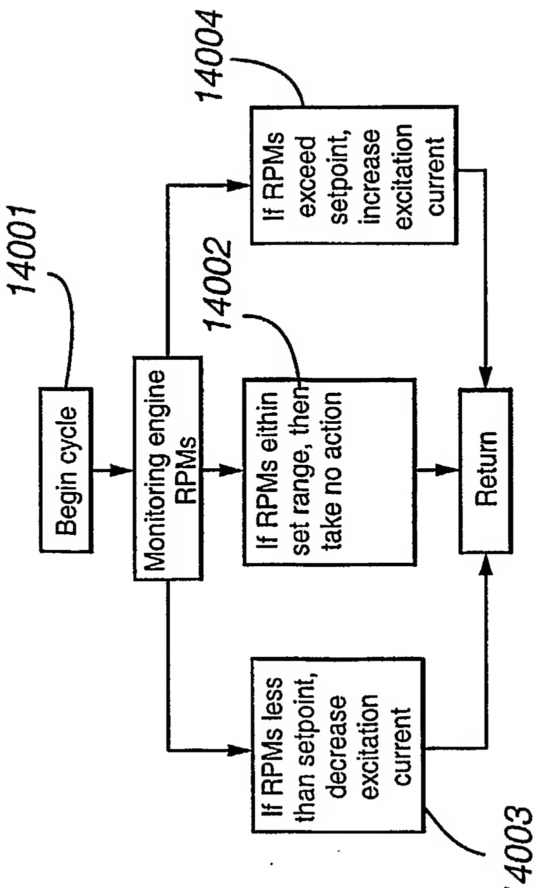



Fig. 14a

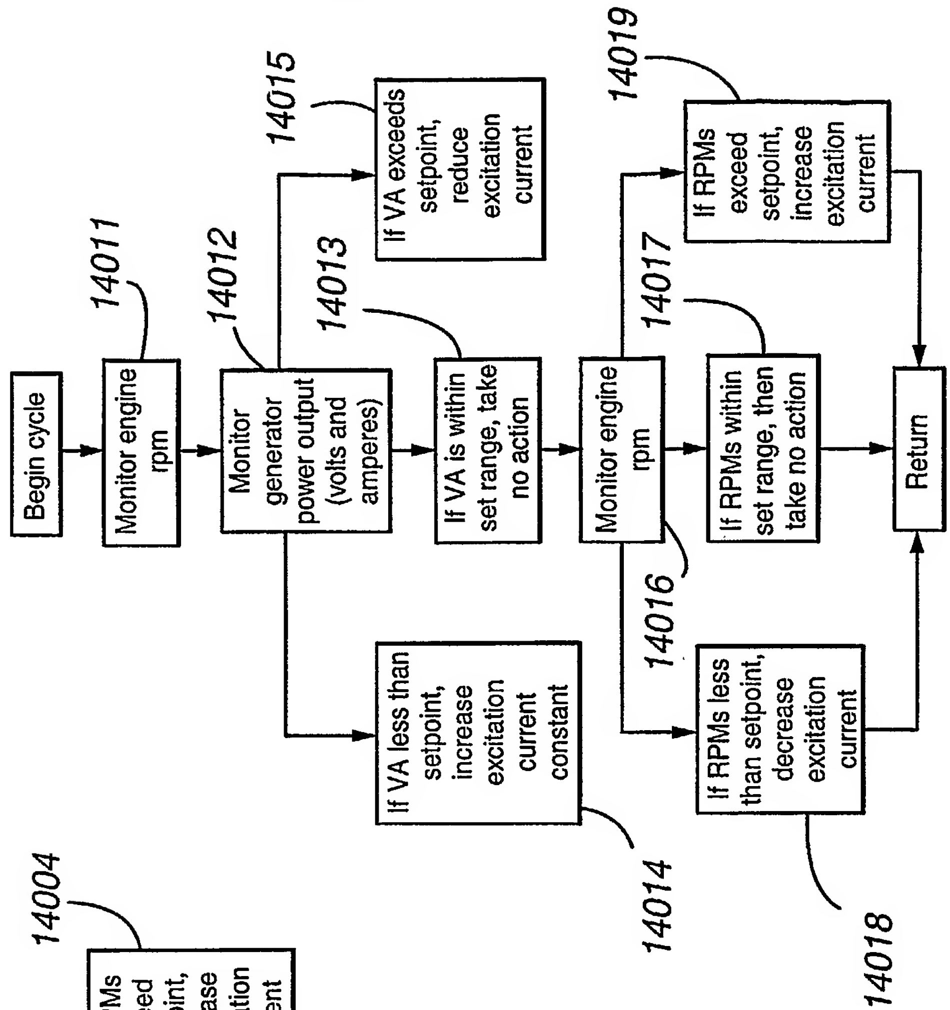



Fig. 14b

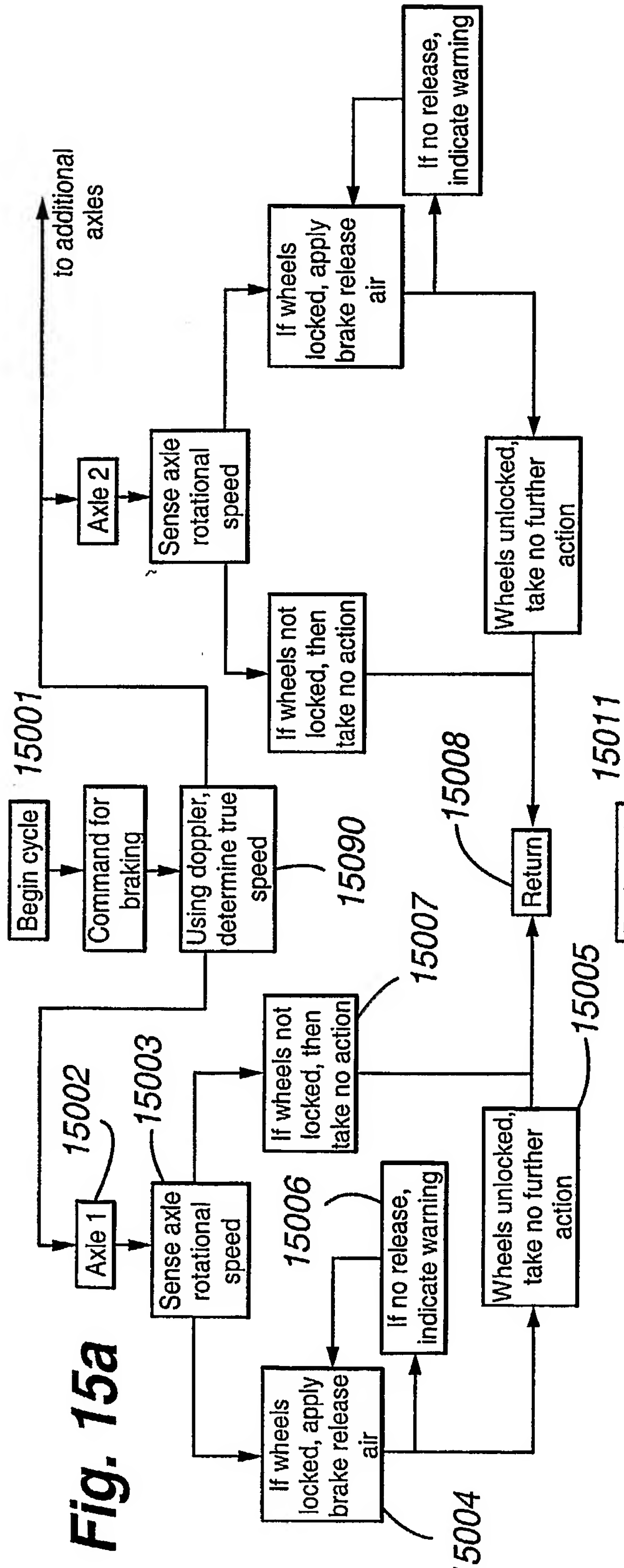



Fig. 15a

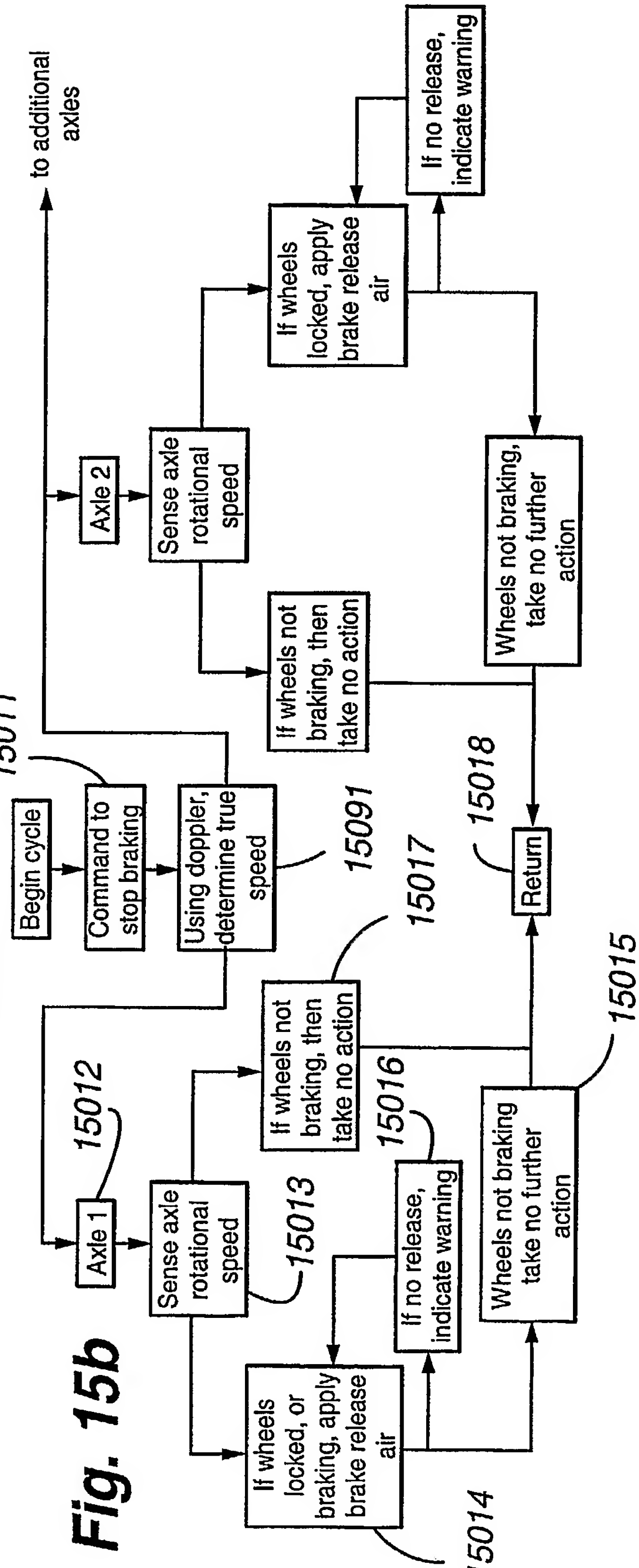



Fig. 15b

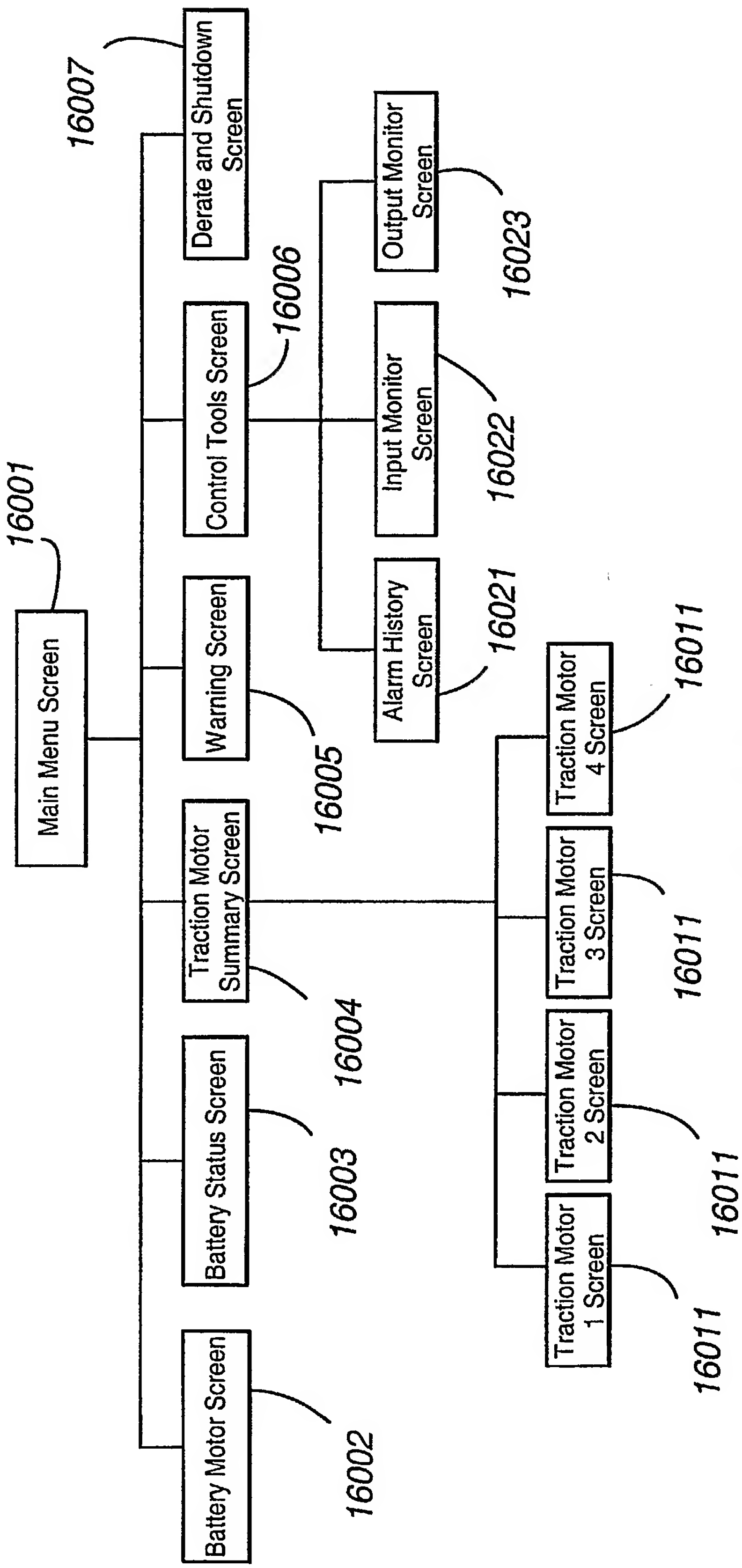

Main Menu Screen
16001
Battery Motor Screen
16002
Battery Status Screen
16003
Traction Motor Summary Screen
16004
Warning Screen
16005
Control Tools Screen
16006
Derate and Shutdown Screen
16007
Alarm History Screen
16021
Input Monitor Screen
16022
Output Monitor Screen
16023
Traction Motor 1 Screen
16011
Traction Motor 2 Screen
16011
Traction Motor 3 Screen
16011
Traction Motor 4 Screen
16011

Fig. 16

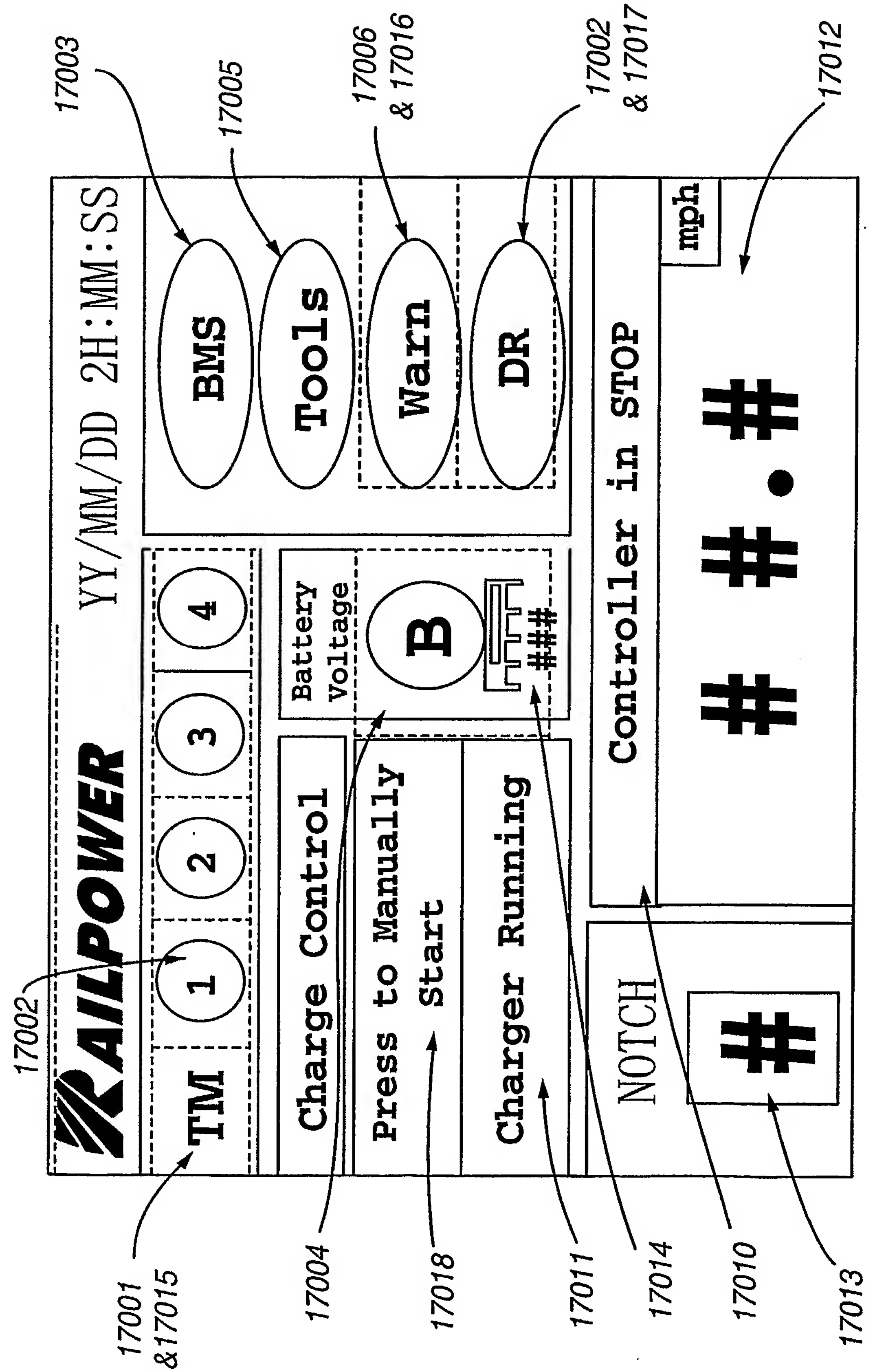

YY/MM/DD 2H:MM:SS
RAILPOWER
TM
1
2
3
4
BMS
Tools
Warn
DR
Battery Voltage
B
###
Charge Control
Press to Manually Start
Charger Running
Controller in STOP
mph
## . #
NOTCH
#
17001 &17015
17002
17002 & 17017
17003
17004
17005
17006 & 17016
17010
17011
17012
17013
17014
17018

*Fig. 17*

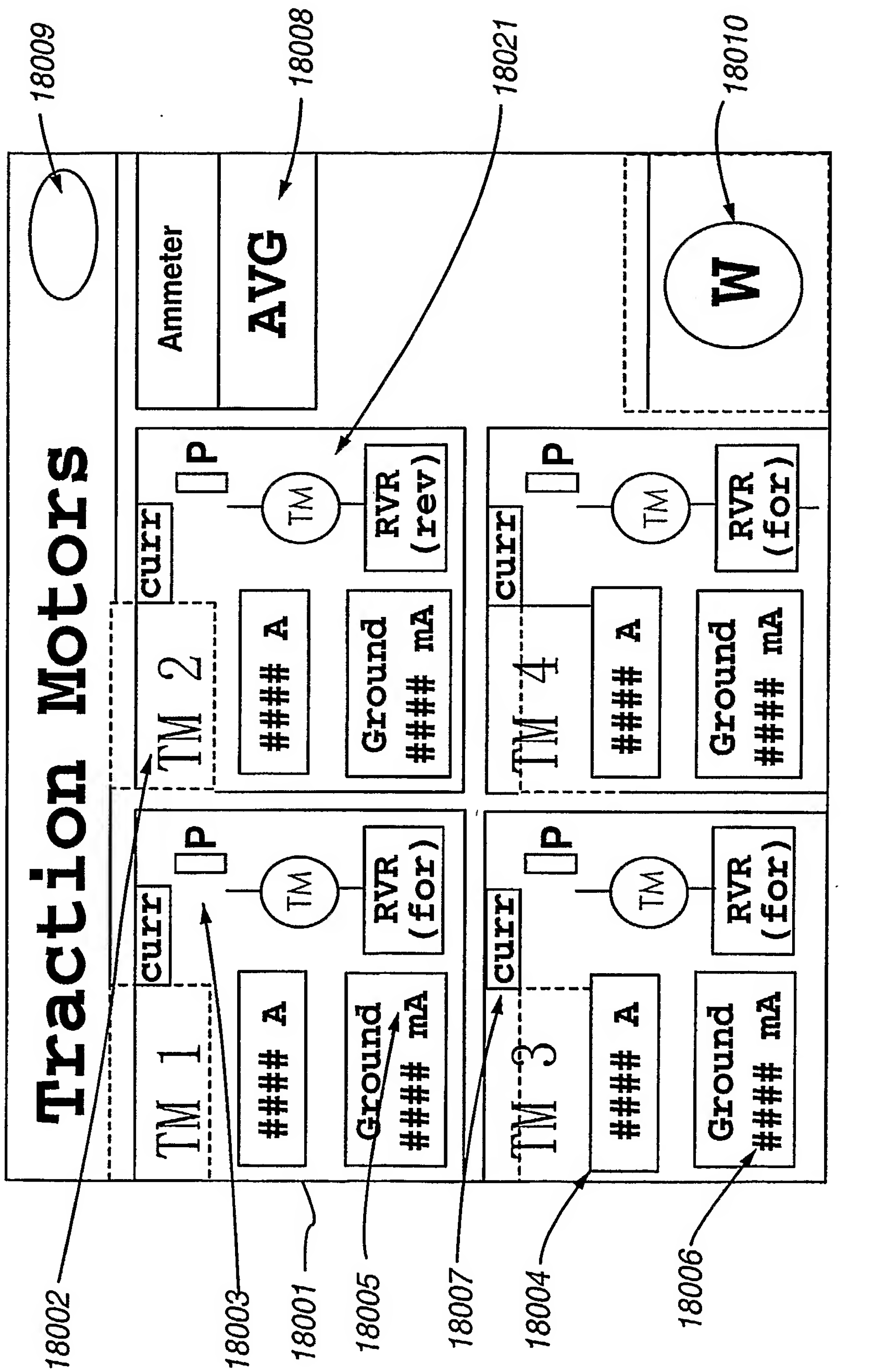

Traction Motors
Ammeter
AVG
W
TM 1
TM 2
TM 3
TM 4
curr
P
TM
RVR (for)
RVR (rev)
#### A
Ground #### mA
18001
18002
18003
18004
18005
18006
18007
18008
18009
18010
18021

Fig. 18

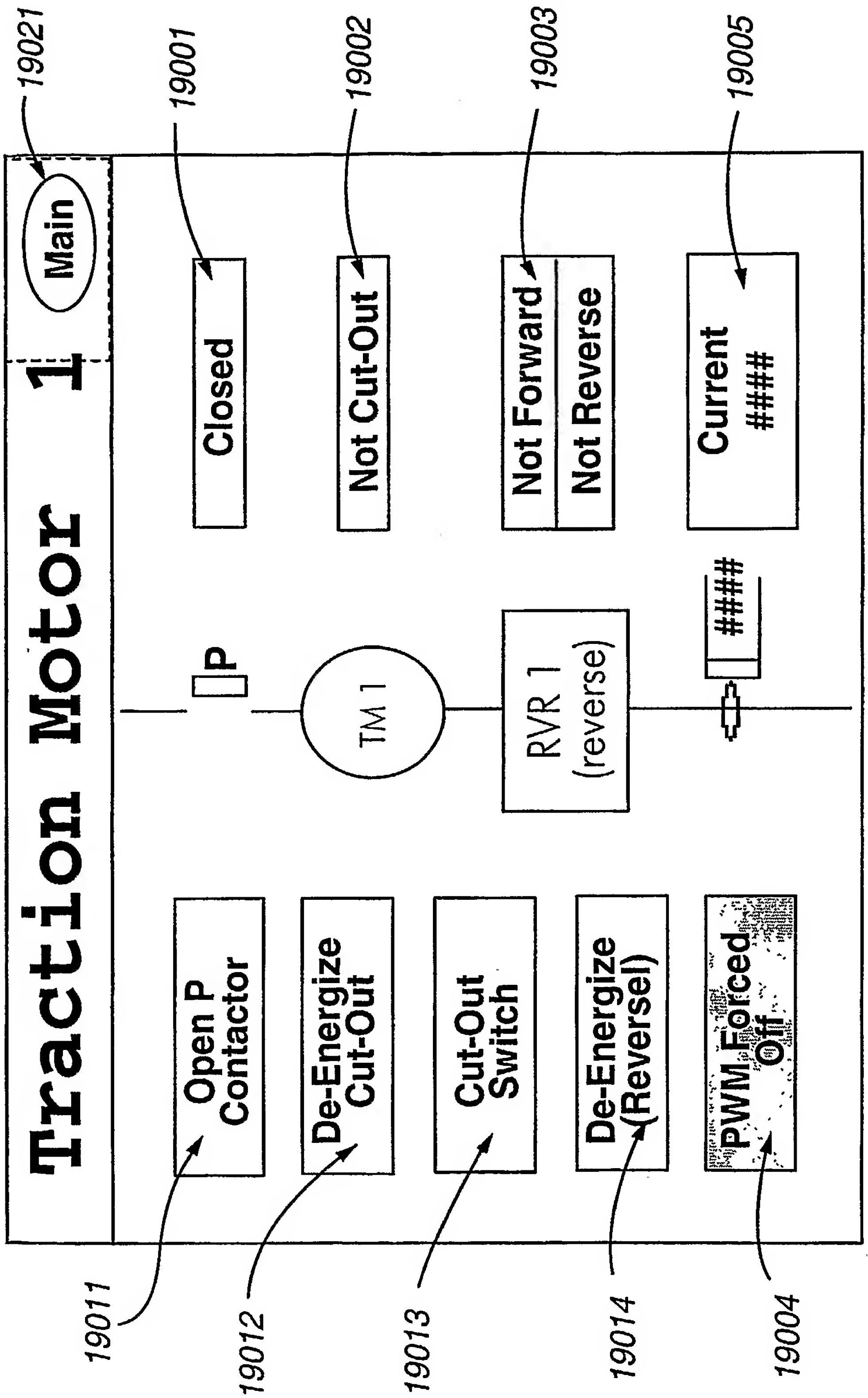

Traction Motor 1
Main
19021
19001
19002
19003
19005
Closed
Not Cut-Out
Not Forward
Not Reverse
Current
####
P
TM 1
RVR 1
(reverse)
####
Open P Contactor
De-Energize Cut-Out
Cut-Out Switch
De-Energize (Reversel)
PWM Forced Off
19011
19012
19013
19014
19004

Fig. 19

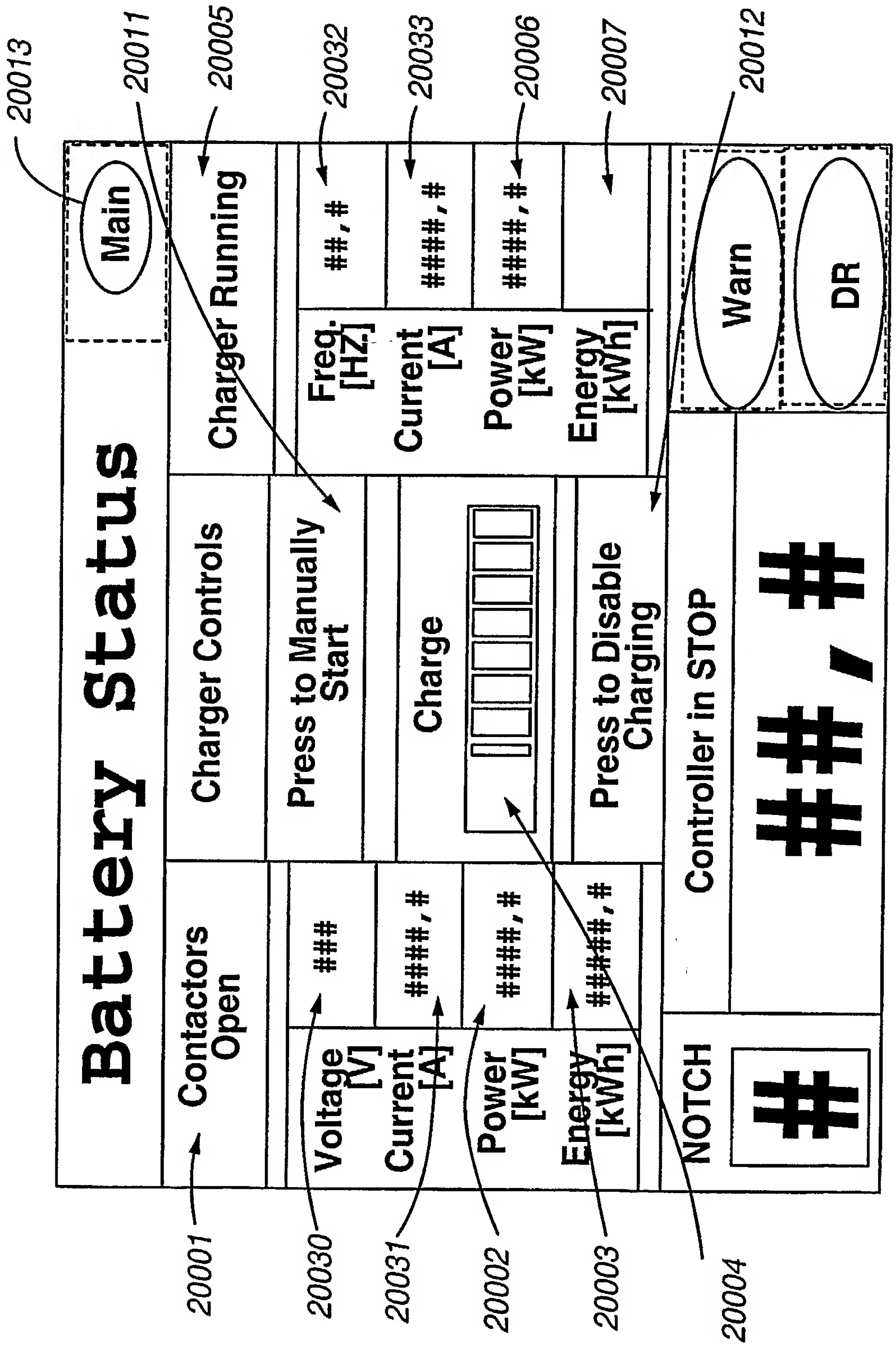

Battery Status
Main
Contactors Open
Charger Controls
Charger Running
Press to Manually Start
Charge
Press to Disable Charging
Voltage [V]
Current [A]
Power [kW]
Energy [kWh]
###
####,#
####,#
#####,#
Freq. [HZ]
Current [A]
Power [kW]
Energy [kWh]
##,#
####,#
####,#
Warn
DR
Controller in STOP
NOTCH
#
##,#
20013
20011
20005
20032
20033
20006
20007
20012
20001
20030
20031
20002
20003
20004

*Fig. 20*

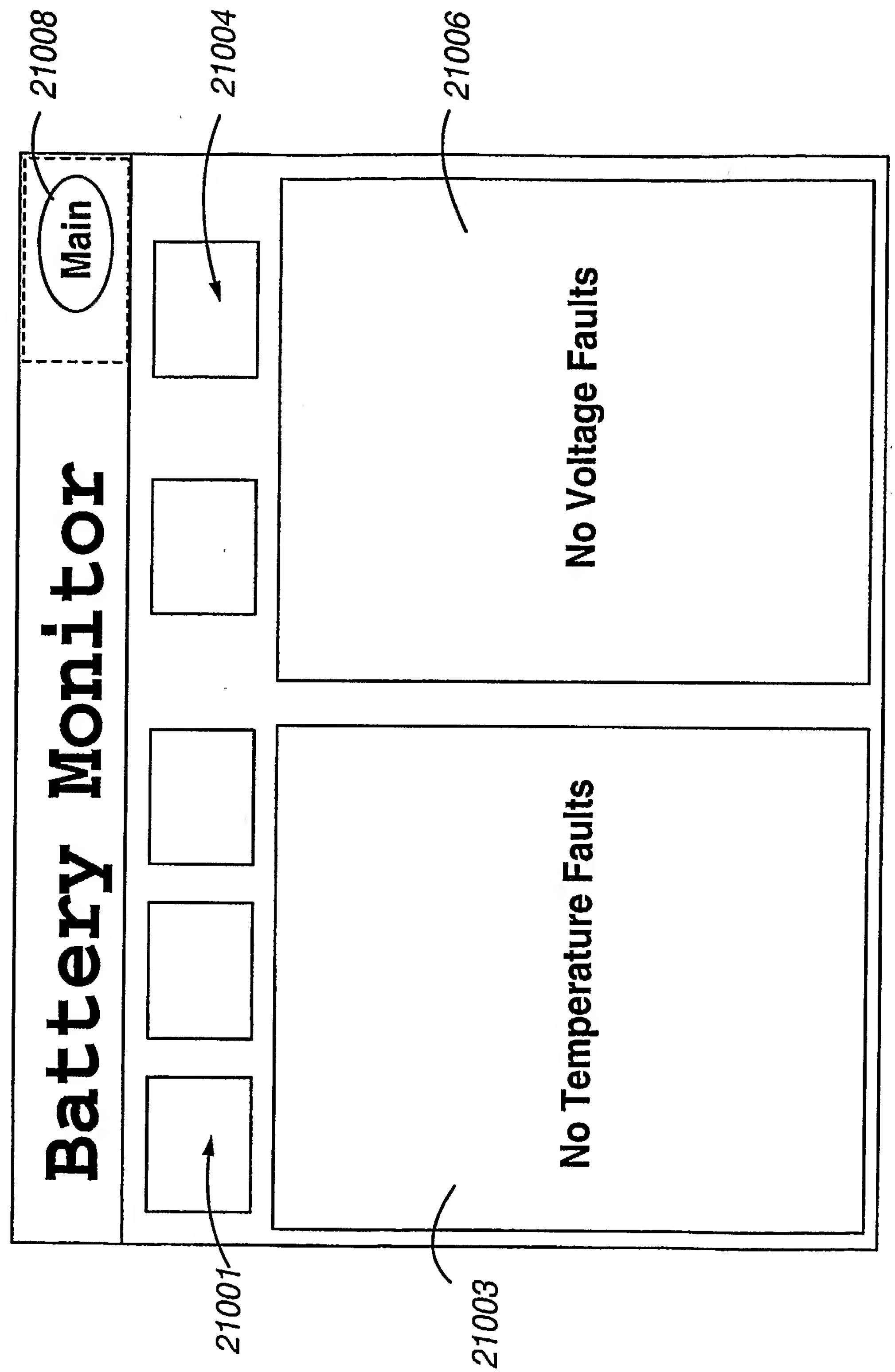

21008
21004
21006
Main
Battery Monitor
No Voltage Faults
No Temperature Faults
21001
21003

Fig. 21

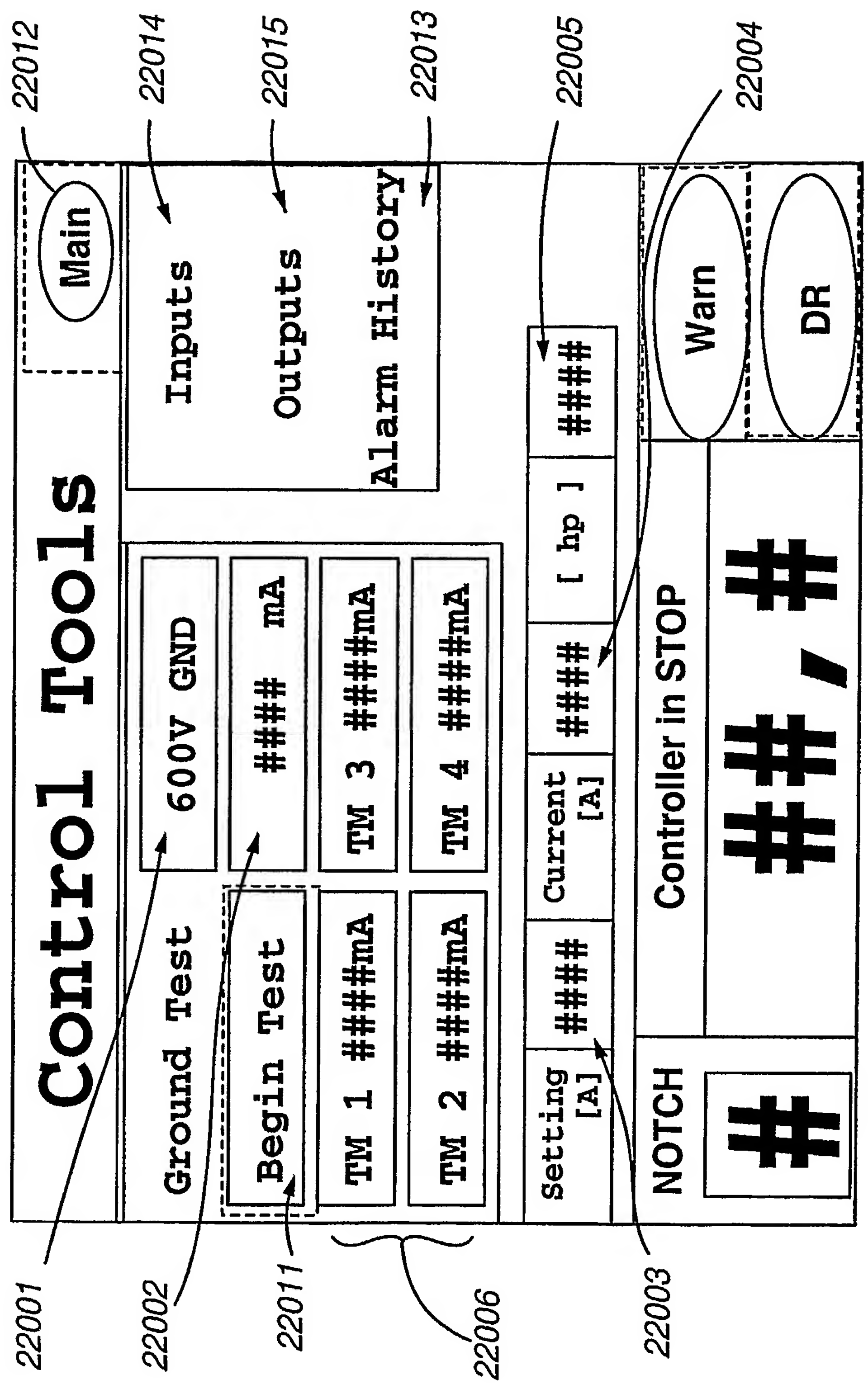

Control Tools
Main
Inputs
Outputs
Alarm History
Ground Test
600V GND
Begin Test
#### mA
TM 1 ####mA
TM 2 ####mA
TM 3 ####mA
TM 4 ####mA
Setting [A]
####
Current [A]
####
[ hp ]
####
Warn
DR
NOTCH
#
Controller in STOP
## / #
22001
22002
22011
22006
22003
22012
22014
22015
22013
22005
22004

Fig. 22

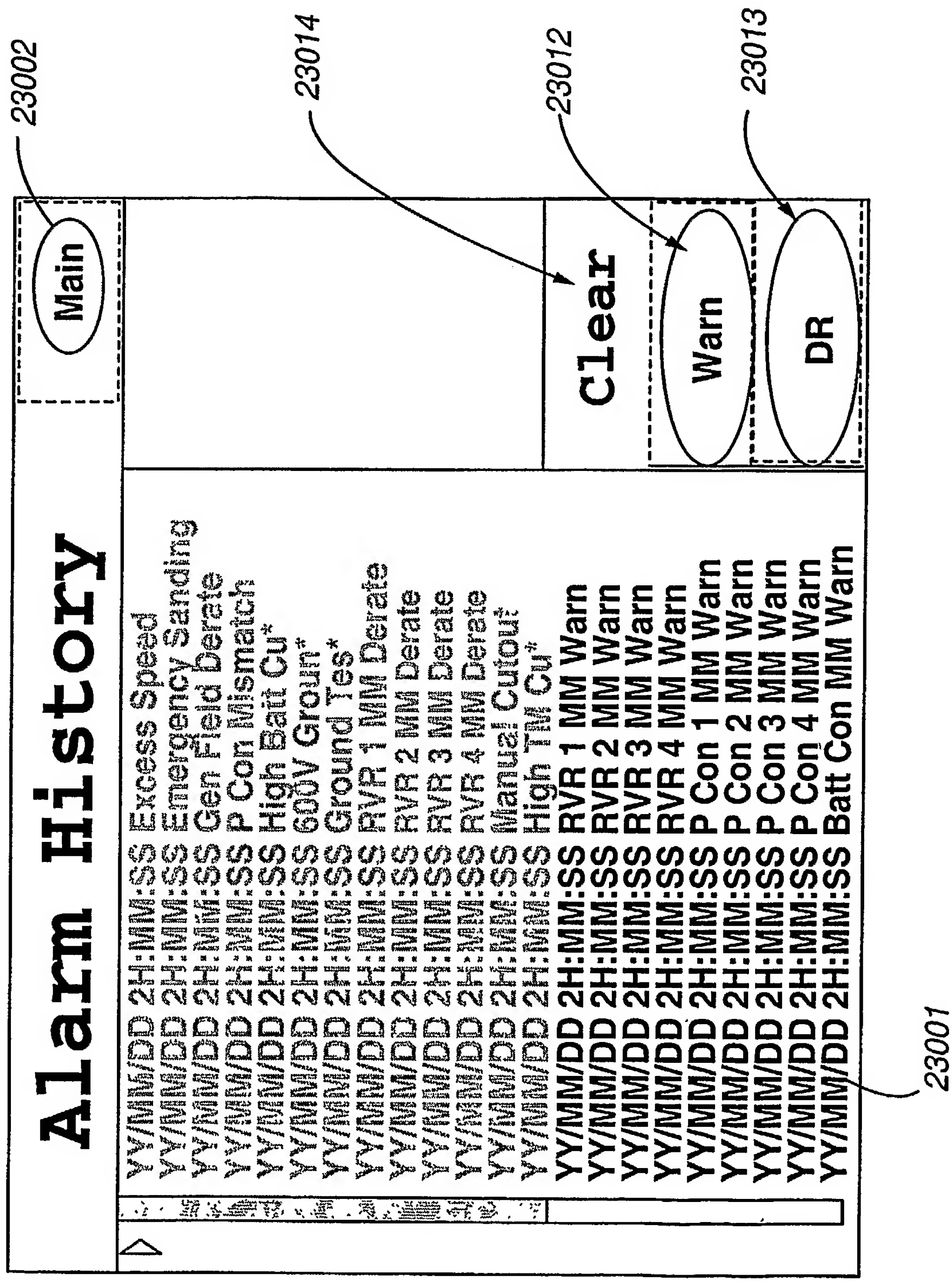

Alarm History
Main
Clear
Warn
DR
YY/MM/DD 2H:MM:SS Excess Speed
YY/MM/DD 2H:MM:SS Emergency Sanding
YY/MM/DD 2H:MM:SS Gen Field Derate
YY/MM/DD 2H:MM:SS P Con Mismatch
YY/MM/DD 2H:MM:SS High Batt Cu*
YY/MM/DD 2H:MM:SS 600V Groun*
YY/MM/DD 2H:MM:SS Ground Tes*
YY/MM/DD 2H:MM:SS RVR 1 MM Derate
YY/MM/DD 2H:MM:SS RVR 2 MM Derate
YY/MM/DD 2H:MM:SS RVR 3 MM Derate
YY/MM/DD 2H:MM:SS RVR 4 MM Derate
YY/MM/DD 2H:MM:SS Manual Cutout
YY/MM/DD 2H:MM:SS High TM Cu*
YY/MM/DD 2H:MM:SS RVR 1 MM Warn
YY/MM/DD 2H:MM:SS RVR 2 MM Warn
YY/MM/DD 2H:MM:SS RVR 3 MM Warn
YY/MM/DD 2H:MM:SS RVR 4 MM Warn
YY/MM/DD 2H:MM:SS P Con 1 MM Warn
YY/MM/DD 2H:MM:SS P Con 2 MM Warn
YY/MM/DD 2H:MM:SS P Con 3 MM Warn
YY/MM/DD 2H:MM:SS P Con 4 MM Warn
YY/MM/DD 2H:MM:SS Batt Con MM Warn
23002
23014
23012
23013
23001

*Fig. 23*

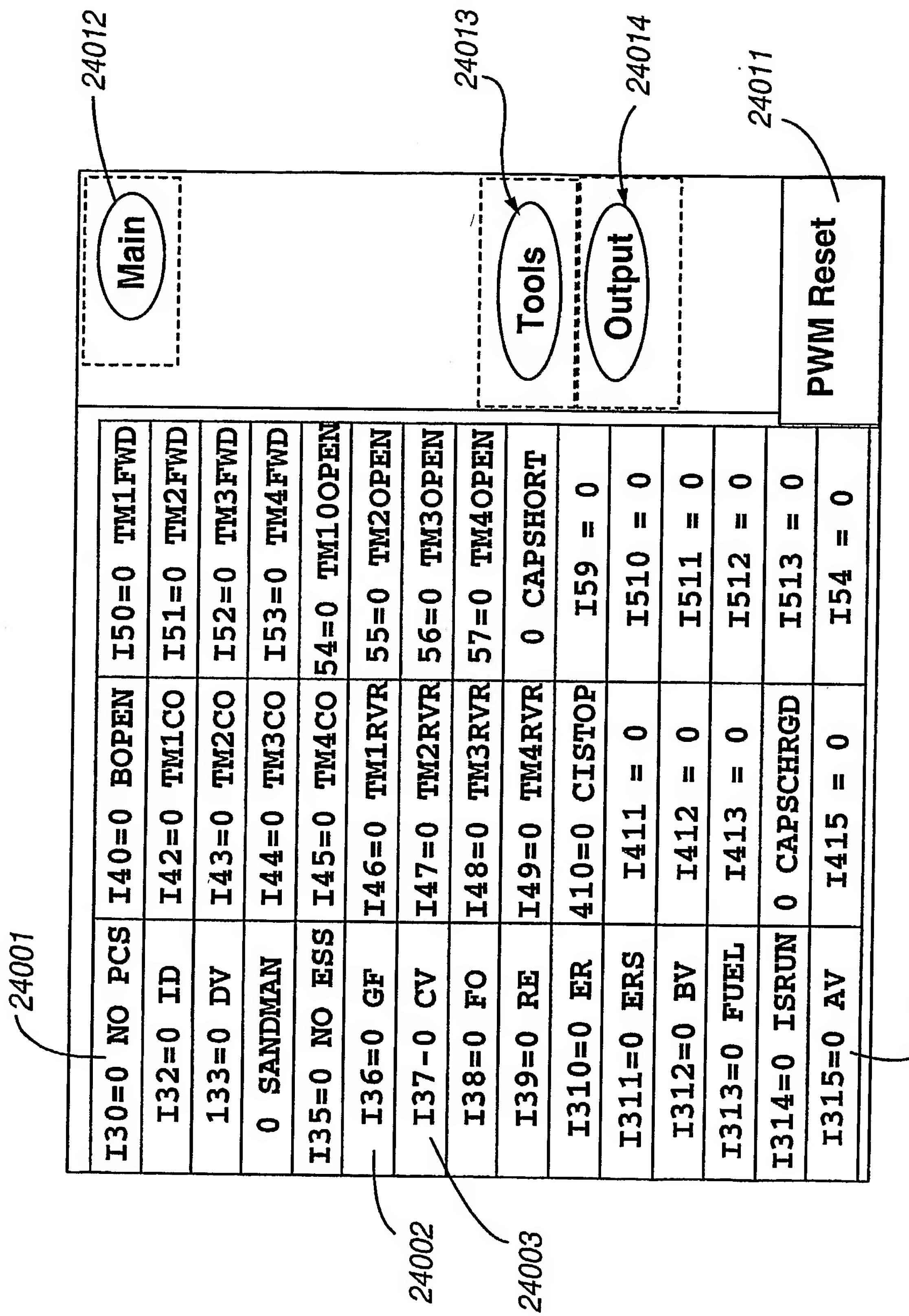
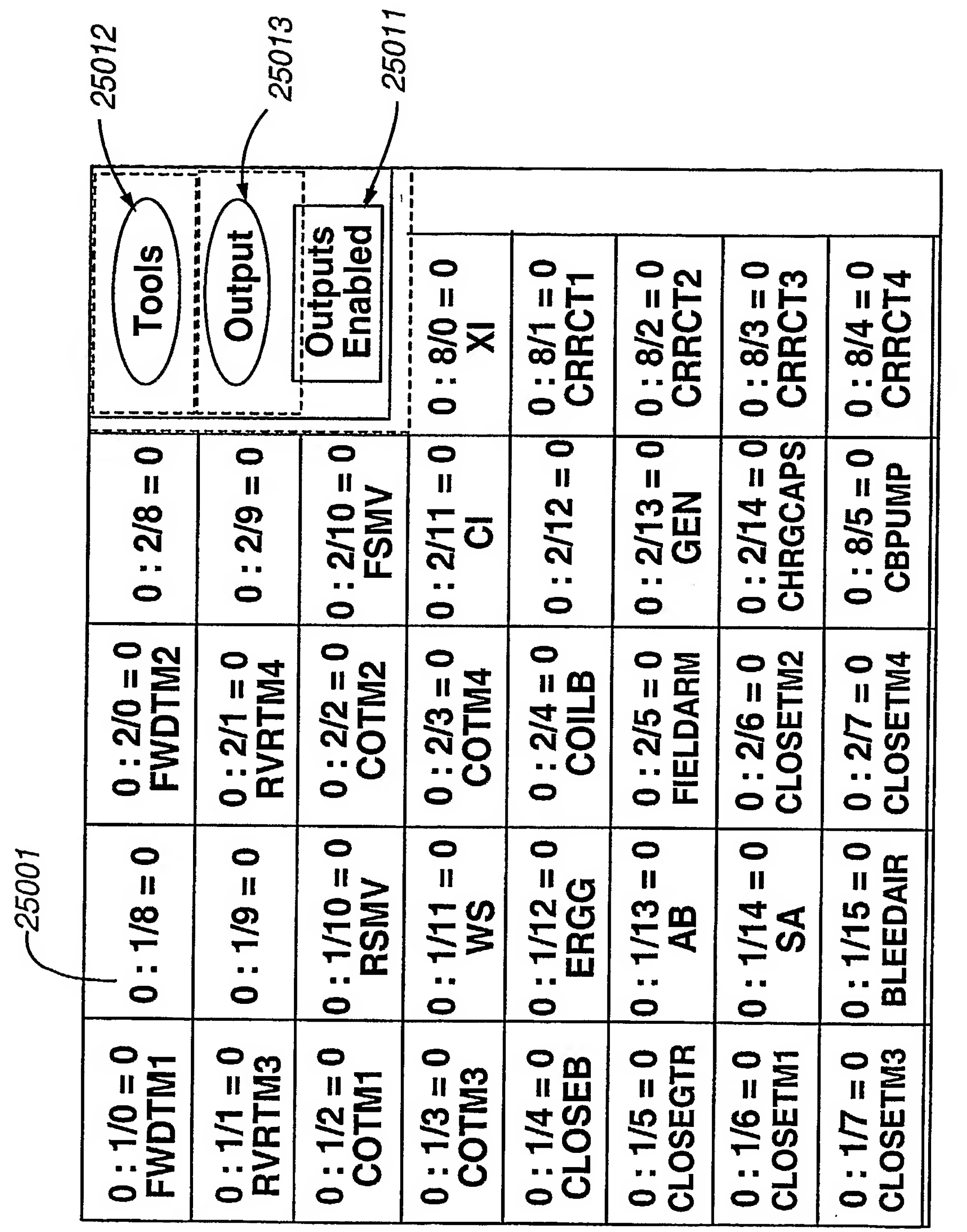

24012
24013
24014
24011
Main
Tools
Output
PWM Reset
I30=0 NO PCS
I40=0 BOPEN
I50=0 TM1FWD
I32=0 ID
I42=0 TM1CO
I51=0 TM2FWD
133=0 DV
I43=0 TM2CO
I52=0 TM3FWD
0 SANDMAN
I44=0 TM3CO
I53=0 TM4FWD
I35=0 NO ESS
I45=0 TM4CO
54=0 TM1OOPEN
I36=0 GF
I46=0 TM1RVR
55=0 TM2OPEN
I37-0 CV
I47=0 TM2RVR
56=0 TM3OPEN
I38=0 FO
I48=0 TM3RVR
57=0 TM4OPEN
I39=0 RE
I49=0 TM4RVR
0 CAPSHORT
I310=0 ER
410=0 CISTOP
I59 = 0
I311=0 ERS
I411 = 0
I510 = 0
I312=0 BV
I412 = 0
I511 = 0
I313=0 FUEL
I413 = 0
I512 = 0
I314=0 ISRUN
0 CAPSCHRGD
I513 = 0
I315=0 AV
I415 = 0
I54 = 0
24001
24002
24003
24004

Fig. 24



25012
25013
25011
25001
Tools
Output
Outputs Enabled
0 : 1/0 = 0 FWDTM1
0 : 1/8 = 0
0 : 2/0 = 0 FWDTM2
0 : 2/8 = 0
0 : 1/1 = 0 RVRTM3
0 : 1/9 = 0
0 : 2/1 = 0 RVRTM4
0 : 2/9 = 0
0 : 1/2 = 0 COTM1
0 : 1/10 = 0 RSMV
0 : 2/2 = 0 COTM2
0 : 2/10 = 0 FSMV
0 : 1/3 = 0 COTM3
0 : 1/11 = 0 WS
0 : 2/3 = 0 COTM4
0 : 2/11 = 0 CI
0 : 8/0 = 0 XI
0 : 1/4 = 0 CLOSEB
0 : 1/12 = 0 ERGG
0 : 2/4 = 0 COILB
0 : 2/12 = 0
0 : 8/1 = 0 CRRCT1
0 : 1/5 = 0 CLOSEGTR
0 : 1/13 = 0 AB
0 : 2/5 = 0 FIELDARM
0 : 2/13 = 0 GEN
0 : 8/2 = 0 CRRCT2
0 : 1/6 = 0 CLOSETM1
0 : 1/14 = 0 SA
0 : 2/6 = 0 CLOSETM2
0 : 2/14 = 0 CHRGCAPS
0 : 8/3 = 0 CRRCT3
0 : 1/7 = 0 CLOSETM3
0 : 1/15 = 0 BLEEDAIR
0 : 2/7 = 0 CLOSETM4
0 : 8/5 = 0 CBPUMP
0 : 8/4 = 0 CRRCT4


*Fig. 25*

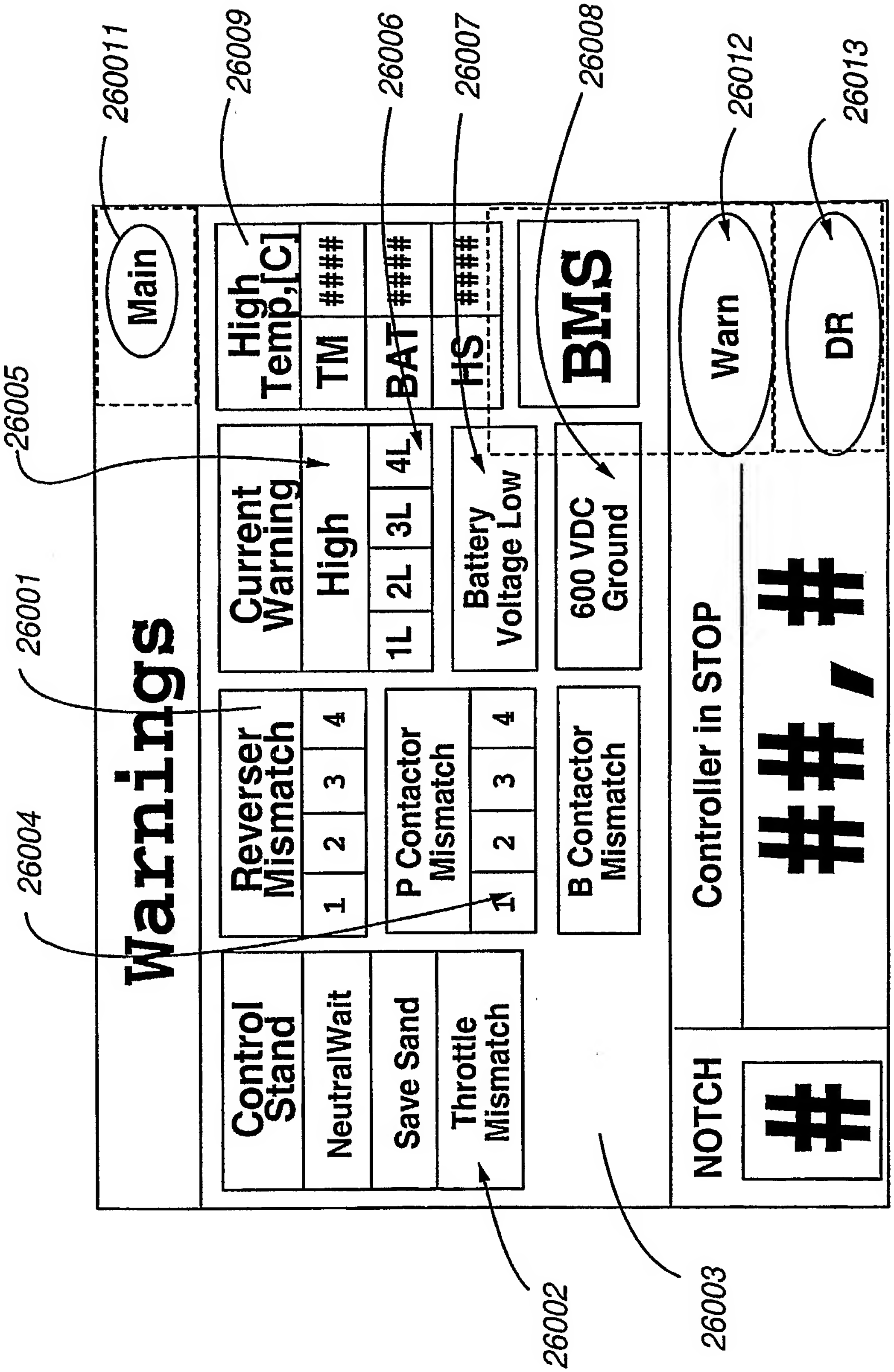
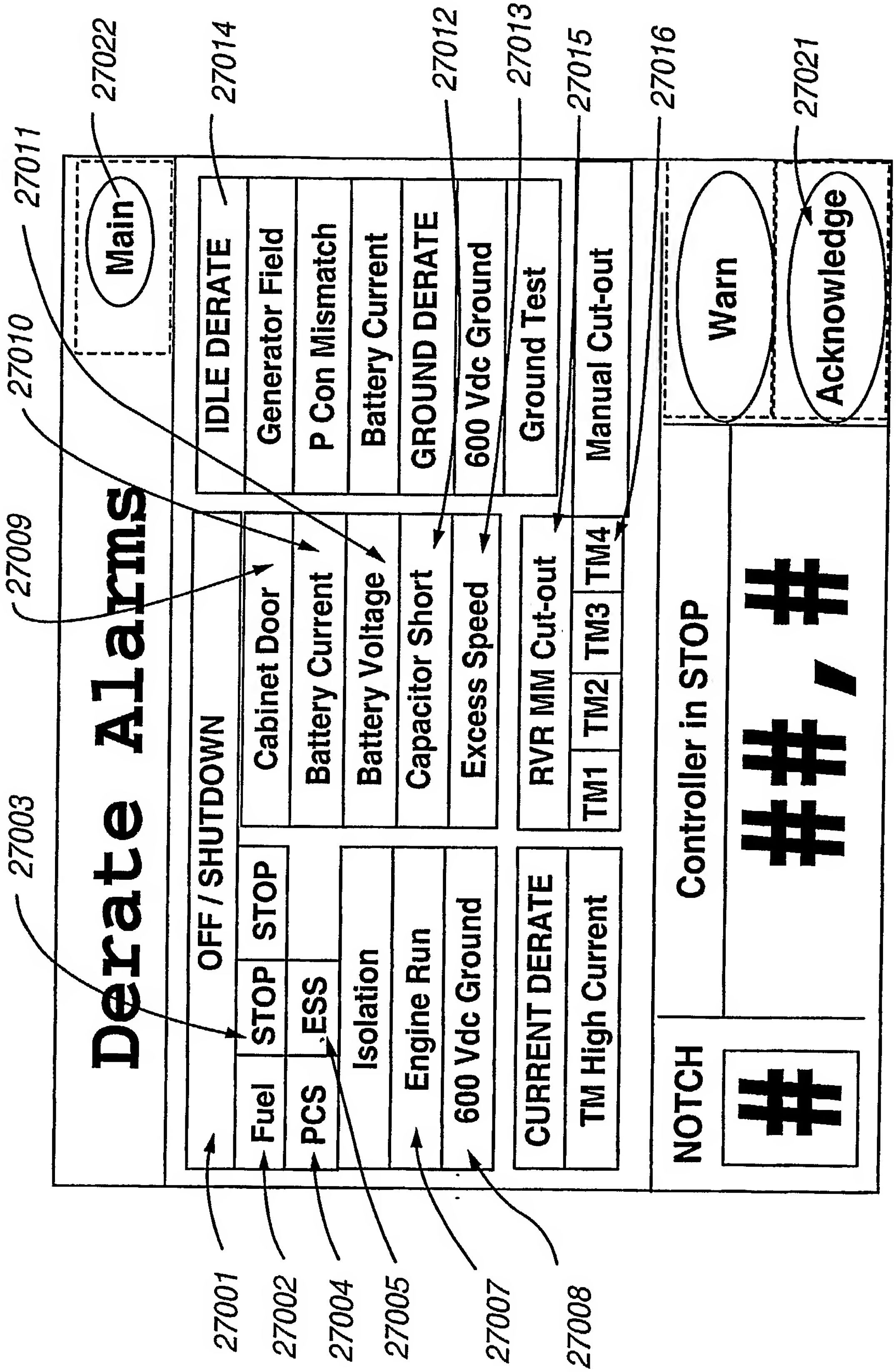

Warnings
Main
Control Stand
NeutralWait
Save Sand
Throttle Mismatch
Reverser Mismatch
1
2
3
4
P Contactor Mismatch
1
2
3
4
B Contactor Mismatch
Current Warning
High
1L
2L
3L
4L
Battery Voltage Low
600 VDC Ground
High Temp,[C]
TM
####
BAT
####
HS
####
BMS
Warn
DR
NOTCH
#
Controller in STOP
###/#
260011
26009
26006
26007
26008
26012
26013
26005
26001
26004
26002
26003

*Fig. 26*



Derate Alarms
Main
OFF / SHUTDOWN
Fuel
STOP
STOP
PCS
ESS
Isolation
Engine Run
600 Vdc Ground
Cabinet Door
Battery Current
Battery Voltage
Capacitor Short
Excess Speed
IDLE DERATE
Generator Field
P Con Mismatch
Battery Current
GROUND DERATE
600 Vdc Ground
Ground Test
CURRENT DERATE
TM High Current
RVR MM Cut-out
TM1
TM2
TM3
TM4
Manual Cut-out
Warn
Acknowledge
NOTCH
#
Controller in STOP
## , ##
27001
27002
27003
27004
27005
27007
27008
27009
27010
27011
27012
27013
27014
27015
27016
27021
27022


Fig. 27

| INTERNATIONAL SEARCH REPORT | International application No. PCT/US03/26994 |
|---|---|

**A. CLASSIFICATION OF SUBJECT MATTER**
IPC(7) : B 61 C 11/00, 13/00, 3/00
US CL : 105/26.05, 49, 50
According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 105/26.05, 49, 50

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Please See Continuation Sheet

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category * | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| A | US 4,900,944 A (Donnelly) 13 February 1990 (13.02.1990), whole document. | 1-30 |
| A | US 5,392,716 A (Orschek et al (28 February 1995) (28.02.1995), whole document. | 1-30 |
| A | US 5,661,378 A (Hapeman) 26 August 1997 (26.08.1997), whole document. | 1-30 |
| A | US 5,735,215 A (Tegler) 07 April 1998 (07.04.1998), whole document | 1-30 |
| A,E | US 6,612,246 B2 (Kumar) 02 September 2003 (02.09.2003) | 1-30 |

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 26 February 2004 (26.02.2004) | 12 MAR 2004 |
| Name and mailing address of the ISA/US<br>Mail Stop PCT, Attn: ISA/US<br>Commissioner for Patents<br>P.O. Box 1450<br>Alexandria, Virginia 22313-1450<br>Facsimile No. (703)305-3230 | Authorized officer<br>For S. Joseph Morano P. Volpe<br>Telephone No. (703) 308-1113 |

# INTERNATIONAL SEARCH REPORT

**Continuation of B. FIELDS SEARCHED Item 3:**
EAST
search terms: locomotive, battery, traction motor, chopper circuit